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14. ABSTRACT

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Acronym List

ADU	Attitude determination unit
AF	Airfield (APG site)
AGL	Above ground level
ALASA	As low as safely allowable
APG	Aberdeen Proving Ground
ARF	Active Recovery Field (APG site)
AS	Analytic signal
ASCII	American Standard Code for Information Interchange
ATC	Aberdeen Test Center
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
DAS	Data analysis system
DoD	Department of Defense
DP	Dewatering Ponds (APG site)
DQO	Data Quality Objective
DSHE	Directorate of Safety, Health, and Environment (APG)
ESTCP	Environmental Security Technology Certification Program
FAA	Federal Aviation Administration
FUDS	Formerly Used Defense Site
GIS	Geographic Information System
GPS, DGPS	(Differential) Global Positioning System
HAZWOPR	Hazardous Waste Operations and Emergency Response
INS	U.S. Immigration and Naturalization Service
MGD	Mine, Grenade and Direct-fire Weapon Range (APG site)
MTADS	Multi-Sensor Towed Array Detection System
NAD	North American Datum
ORAGS	Oak Ridge Airborne Geophysical System
ORNL	Oak Ridge National Laboratory
SERDP	Strategic Environmental Research & Development Program
TIF, GeoTIF	(Geographically referenced) Tagged Information File
TF	Total (magnetic) field
USAESCH	U.S. Army Engineering and Support Center, Huntsville
UTM	Universal Transverse Mercator
UXO	Unexploded Ordnance

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Abstract

This report describes the results of a low altitude helicopter geophysical survey performed by Oak Ridge National Laboratory (ORNL) and the U.S. Army Engineering Support Center, Huntsville (USAESCH) over four selected areas at Aberdeen Proving Ground, Maryland in July 2002. The purpose of the survey was to evaluate improvements to a multi-sensor magnetometer system for ordnance detection. The four sites that were surveyed are designated Active Recovery Field for indirect-fire weapons (ARF), Mine, grenade and direct-fire weapon range (MGD), Dewatering Ponds –non-tidal – historically clear of UXO (DP), and Airfield – historically clear of UXO (AF). The average rate of coverage for the three suspected target sites was 91 acres/hr (36.6 ha/hr) and the average survey speed was 10.5 m/s. The average distance between the actual locations of the excavated items and the predicted locations from helicopter anomalies was consistently less than 1m for a 2m search radius. Noise levels were higher than we typically observe, with an average value of 1.7nT in the raw data. The Figure of Merit, an estimate of noise remaining after compensation, is also high. High noise levels indicate that the helicopter created more interference than usual, despite being degaussed four months prior to the survey. Similarly, mean altitude during the survey was greater than at most other sites, 2.9 m average over the entire area.

The most complete performance results were obtained at the Active Recovery Field (ARF) where ground truth included both seeded items (blind) and intrusive excavations were based on airborne picks (double-blind). The ORAGS-Arrowhead performance in the ARF double-blind test (UXO detection excluding seed items) ranged from 86-98% Pd depending on the search radius (1.0m, 1.5m and 2.0m). This performance was based on analysis of data from the ARF site using the UV or MV prioritization methods (Table 4.4). The Pd of seeded items was much lower, for reasons that are still not completely clear. Locations of many of the seeded items coincided with portions of the survey area where data acquisition altitude was particularly high, which led to poorer performance in this category, although survey altitude does not fully explain the difference.

The statistical classification approach proved more effective than the manual DAS procedure applied to these data. The average priority assigned to ordnance items for each of the three techniques was 2.75 and 2.89 for multivariate and univariate classification respectively, and 4.37 for the DAS analysis on a scale of 1-6 from most to least likely to be ordnance.

1.0 Introduction

1.1 Background

Portions of Aberdeen Proving Ground (APG), Maryland, have been contaminated with unexploded ordnance (UXO) through Department of Defense (DoD) training exercises or during weapons tests. Several sites in the APG have been surveyed as part of ESTCP projects. The airborne technology offers an approach for rapid reconnaissance of large UXO-contaminated sites which are common at DoD sites, particularly in the western United States.

This report describes the logistics and results of an airborne geophysical survey performed by Oak Ridge National Laboratory (ORNL) at Aberdeen Proving Ground (APG), Maryland. Four areas, totaling 348 acres (141 hectares) and located within the APG site, were surveyed. The areas are referred to as Dewatering Ponds – non-tidal – historically clear of UXO (DP), 107 acres/ 43 hectares), Mine, Grenade, and Direct-fire weapon range (MGD, 124 acres/ 50 hectares), Active Recovery Field for indirect-fire weapons (ARF, 102 acres/ 41 hectares) and Airfield, Historically Clear of UXO (AF, 14 acres/ 5.7 hectares, Figure 1.1). Supplemental passes were flown over a test grid that was established by APG staff, immediately adjacent to the AF area. The test site and portions of MGD and AF were also surveyed with an experimental vertical magnetic gradient system. This portion of the APG survey is included in a separate report to ESTCP on the vertical gradient system, and includes survey results from two other ESTCP sites. A fifth area, a tidal site of old impact areas in Chesapeake Bay, was a candidate for airborne surveying, but did not meet FAA requirements for operation of the airborne system because surveys over such large areas of open water require flotation equipment or twin engine aircraft. APG staff provided all survey area boundaries in advance.

The survey was flown from July 22 through July 29, 2002. Mobilization of field crews began on July 19. After arrival of the aircraft and crew on July 20, installation and calibration flights were conducted. Standard format data were acquired between July 23 and July 26, and the vertical magnetic gradient data were acquired on July 27 and 28. The purpose of the survey was to detect ferrous unexploded ordnance (UXO) and other ferrous debris that are believed to contribute to potential local environmental contamination. The survey was accomplished by using the Oak Ridge Airborne Geophysical System (ORAGS™) Arrowhead magnetometer array. The information from these sensors was processed to produce maps that display the magnetic properties of the survey area. A Global Positioning System (GPS) electronic navigation system, utilizing a satellite link for real-time differential corrections, ensured accurate positioning for navigational purposes. Differential post-processing provided more accurate positioning of the geophysical data with respect to the base maps and for Geographic Information System (GIS) interfacing.

Lines were flown in an east-west or north-south pattern depending on local logistics and weather conditions at nominal 12m line spacing. Average survey altitude was 1.4-3.3m varying in response to topography and vegetation. This was sufficient to detect the majority of ordnance and ferrous debris reported to be in the area. Smaller ordnance items and other fragments, such

as those placed in the calibration grid, are also detectable at this altitude, but are weak and difficult to separate from the background noise.

Figure 1.1. Airphoto showing calibration grid (checkout) and Airfield (open field) sites at Aberdeen Proving Ground.

1.2 Objectives of the Demonstration

The objectives of the demonstration survey are:

- To provide a means of determining the improvement resulting from recent modification in the ORAGS total field magnetometer system;
- To assess the capabilities of the system at a site representing conditions and ordnance types typically found on former DoD ranges;
- To detect and map UXO and UXO-related items for subsequent clearance actions.

The survey was carried out using the ORAGS-Arrowhead magnetometer array. Data were also acquired with the ORAGSA-VG vertical magnetic gradient system over selected areas.

1.3 Regulatory Drivers

UXO clearance is generally conducted under CERCLA authority. Attempts to establish a "Range Rule" have been abandoned. Irrespective of lack of specific regulatory drivers, many DoD sites and installations are pursuing innovative technologies to address a variety of issues associated with ordnance and ordnance-related artifacts (e.g. buried waste sites or ordnance

caches) that resulted form weapons testing and/or training activities. These issues include footprint reduction and site characterization, areas of particular focus for the application of technologies in advance of future regulatory drivers and mandates.

1.4 Stakeholder/End-User Issues

The APG sites are active DoD ranges. The data collected at these sites are to be used primarily for evaluation of the ORAGS helicopter geophysical systems, rather than for ordnance remediation. However, maps of concentrations of ordnance and locations of possibly live ordnance can be used in the near-term in UXO removal actions and safeguards can be established where there is the possibility that live ordnance is still in place. It is also important that a permanent record be maintained to document all measurements that are made to support clearance activities. Advanced technology is expected to contribute to the performance of these activities in terms of efficiency as well as cost.

2.0 Technology Description

2.1 Technology Development and Application

The total field system is a fourth-generation airborne magnetometer array (Figures 2.1 and 2.2) that we have designated as the ORAGS-Arrowhead system. Changes from the previous ORNL airborne magnetometer array, the ORAGS-Hammerhead, include a new boom architecture designed to position sensors at low-noise locations, and a new aircraft orientation system. The new attitude determination system is based on four Global Positioning System (GPS) antennas rather than fluxgate magnetometer measurement as in previous generations. For the ORAGS-Arrowhead system, four magnetometers at 1.7-meter spacing are located in a forward V-shaped boom, and two magnetometers with equivalent spacing are located in each of the lateral booms. Although the spacing is similar to that of the predecessor ORAGS-Hammerhead system, the forward positioning of two magnetometers that were previously the innermost rear boom magnetometers on the Hammerhead system improves noise conditions over those of the Hammerhead system.

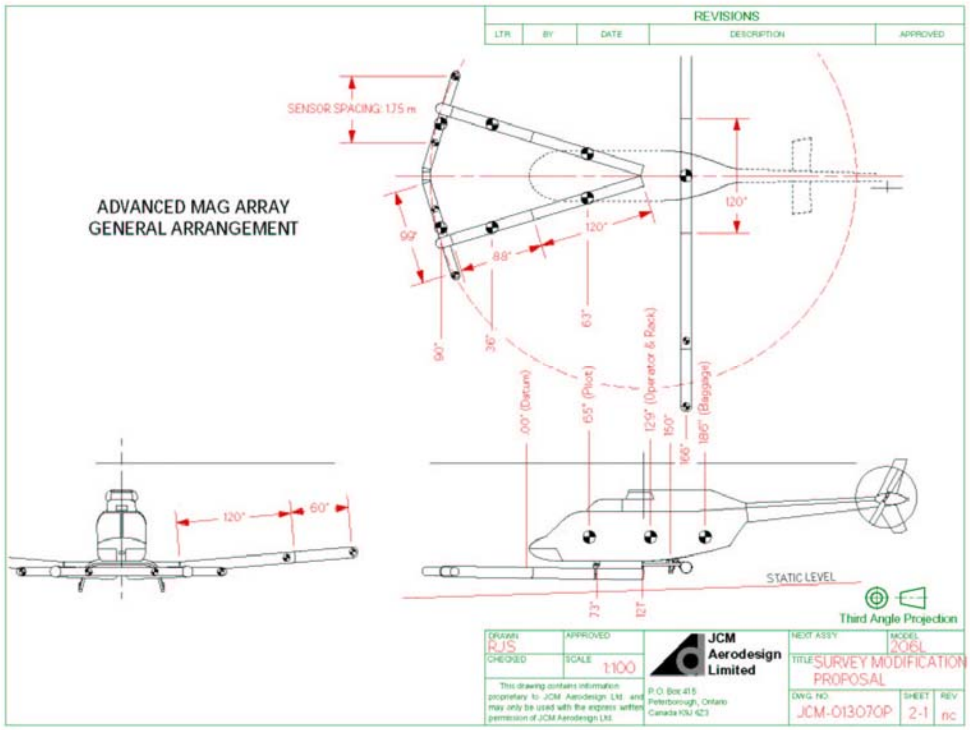


Figure 2.1 Schematic for the ORAGS-Arrowhead airborne total field magnetometer system that has been constructed to evaluate the improvements over previous generations of total field systems.

Figure 2.2 ORAGS-Arrowhead helicopter total field magnetometer system at APG (photo courtesy Gary Rowe, APG).

2.2 Previous Testing of the Technology

ORNL has previously tested two generations of boom-mounted airborne magnetometer systems for UXO detection and mapping. The first system tested was the HM-3 system, depicted in Figure 2.3, developed by Aerodat, Ltd., under the direction of J.S. Holladay and T. J. Gamey. The 1999 airborne magnetometer tests at BBR deployed this system, operated by High Sense Geophysics, and was modified to meet ORNL requirements (Gamey et al., 2000).

In September 2000, ORNL deployed a more advanced helicopter system at BBR, the ORAGS-Hammerhead system, in cooperation with Dr. Holladay (now at Geosensors Inc., a teaming partner with ORNL) and Mr. Gamey (now at ORNL). While somewhat similar in appearance to the HM-3 system, this system, illustrated in Figure 2.4, is significantly improved in terms of the number of magnetometers, magnetometer spacing, system positioning, navigation, and data acquisition parameters (Doll et al., 2001; Gamey et al., 2001). Additionally, a dihedral in the boom tubes improved system safety by raising the boom tips.

In April/May 2002, Arrowhead surveys were conducted at sites on the Pueblos of Laguna and BBR, near Albuquerque, New Mexico.

Figure 2.3 The HM-3 helicopter magnetometer system used by ORNL in 1999 for surveys at Badlands Bombing Range.

Figure 2.4 ORAGS-Hammerhead airborne magnetometer system used at Badlands Bombing Range in FY2000.

2.3 Factors Affecting Cost and Performance

The cost of an airborne survey depends on several factors, including:

- Helicopter service costs, which depend on the cost of ferrying the aircraft to the site and fuel costs, among other factors.
- The total size of the blocks to be surveyed
- The length of flight lines
- The extent of topographic irregularities or vegetation that can influence flight variations and performance
- Ordnance objectives which dictate survey altitude and number of flight lines
- The temperature and season, which control the number of hours that can be flown each day
- The location of the site, which can influence the cost of logistics
- The number of sensors and their spacing; systems with too few sensors may require more flying, particularly if they require interleaving of flight lines
- Survey objectives and density of coverage, specifically high density for individual ordnance detection versus transects for target/impact area delineation and footprint reduction

2.4 Advantages and Limitations of the Technology

Airborne surveys for UXO are capable of providing data for characterizing potential UXO contamination at a site at considerably lower cost than ground-based systems. Current indications are that the survey cost may approach $70.00 per acre under optimal conditions. Furthermore, the data may be acquired and processed in a shorter period of time, thereby reducing the time required for reviewing large areas. Airborne systems are particularly effective at sites having low-growth vegetation and minimal topographic relief. They can also be used where heavy brush or mud makes it difficult to conduct ground-based surveys.

Both airborne and ground magnetometer systems are susceptible to interference from magnetic rocks and magnetic soils. Rugged topography or tall vegetation limits the utility of helicopter systems, necessitating survey heights too high to resolve individual UXO items.

3.0 Demonstration Design

3.1 Performance Objectives

Table 3.1 is a listing of the various performance objectives for this survey.

Table 3.1 – Performance Objectives of Arrowhead Airborne Magnetic System

Type of Performance Objective	Primary Performance Criteria	Expected Performance (Metric)	Actual Performance Objective Met?
Qualitative	Total Field (TF) system aerodynamically stable	Pilot report	Yes
Quantitative	TF system has lower noise than predecessors	Comparison of data sets at test site and elsewhere	Yes
Qualitative/Quantitative	Improved aircraft compensation over previous systems	Comparison of Figure of Merit (FOM) and compensated profiles with those from Hammerhead system data	No
Quantitative	Probability of detection	>90%	No
Quantitative	False alarm rate	6%	Unknown
Quantitative	Location accuracy	<100 cm	No
Quantitative	Survey rate	>40 acres/hr	Yes
Quantitative	Percent site coverage	100%	Yes

3.2 Selecting Test Sites

The airborne survey sites were selected by APG staff for assessment of airborne geophysical systems as wide-area surveillance tools. Airborne data were acquired at the four sites at APG denoted: AF. ARF. MGD, and DP. All sites were remote, but accessible by both road and air, and are reported to contain 60-mm, 81-mm, 105-mm, 155-mm, and other ordnance types.

3.3 Test Site History/Characteristics

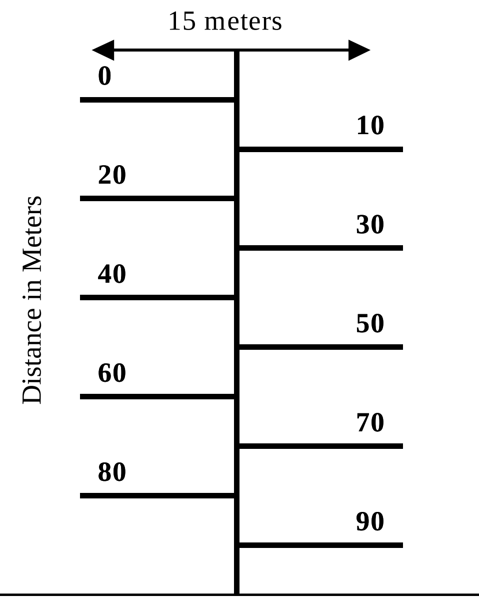
The four APG areas, totaling 348 acres (141 hectares) vary in size. The sizes of the four areas are as follows: DP: 107 acres / 43 hectares; MGD: 124 acres/ 50 hectares; ARF: 102 acres/ 41 hectares; and AF: 14 acres/ 5.7 hectares. Supplemental data were acquired over a test grid that was established by APG staff, immediately adjacent to the AF area. The test site and portions of MGD and AF were also surveyed with an experimental vertical magnetic gradient system. A fifth area, a tidal water site in Chesapeake Bay, was a candidate for airborne surveying, but did not meet FAA requirements for operation of the airborne system because surveys over such large areas of open water require flotation equipment or twin engine aircraft.

3.3.1 Airfield site, historically clear of UXO

The area surrounding the Airfield site (AF) is a flat open field, 38 hectares in area, comprised of loamy soil covered with light vegetation. It was believed that this area is relatively free of clutter and “clear” of UXO.

Two test areas were located at the airfield, a calibration grid and open-field test site. The calibration grid provides an area containing known targets at known locations. This is used to check the responses of sensors before proceeding to the other test sites. The design of the calibration grid is presented in Figure 3.1.

Caliber	Orientation*
60-mm	North-South
81-mm	North-South
2.75-in.	North-South
105-mm	North-South
155-mm	North-South



Caliber	Orientation*
60-mm	East-West
81-mm	East-West
2.75-in.	East-West
105-mm	East-West
155-mm	East-West

* Dip for all items is zero.

Figure 3.1. Design of the Calibration Grid

The open-field test area at the airfield was located in an area that was thought to be a minimum of 50-meters from any interfering anomalies.

3.3.2 Dewatering Ponds (DP)

The Dewatering Ponds site has a total area of 114 hectares, and contains a group of non-tidal ponds. Soil type is loamy with a hard-packed dirt surface and limited vegetation. The maximum depth of the ponds is approximately 2 meters. The total water area is 7 hectares. These ponds are believed to be relatively free of clutter and “clear” of UXO.

3.3.3 Mine, Grenade, and Direct-fire Weapon Range

The MGD site has a total area of 73 hectares. The soil is a silty loam with phragmites (dense vegetation). It is a "high-risk, high-cost" area to emplace targets due to the high concentration of dud grenades, mines, and clutter. UXO present at the site ranges from submunitions to 500 lb. bombs. Ground-truth targets will not be placed in this area; unidentified items will not be recovered from this area. This area is being surveyed for the APG Directorate of Safety, Health, and Environment (DSHE). All ground information will be forwarded to that directorate without being scored.

3.3.4 Active Recovery Field (ARF)

The ARF site is a flat open field encompassing 42 hectares of land area with 8 hectares of beach area. The soil type is silt loam. Vegetation ranges from none to dense growths of phragmites. This field contains a moderate to high concentration of both UXO and metallic clutter with buried ammunition pits. Adjacent to the field is a beach area approximately 8 hectares in size with a shoreline frontage of 1 kilometer. This beach area was selected to evaluate the technology's ability to locate items in a land to water transition site.

3.4 Present Operations

ESTCP contracted APG to prepare the AF calibration site, to provide support during survey operations, and to conduct post-survey validation. The Institute for Defense Analyses (IDA) was contracted by ESTCP to analyze the validation results.

3.5 Pre-Demonstration Testing and Analysis

Shakedown testing of the assembled airborne system and associated components was conducted in Toronto, Ontario, Canada during December 10-21, 2001. These tests were used to determine whether the completed system and its components were performing as designed.

The airborne magnetic system was flight tested by an aeronautical engineer and determined to be completely flightworthy. The testing validated both the aerodynamic stability and performance of the system. Magnetic noise levels for the system were measured both on the ground and during flight. Total magnetic field data were collected at low altitude over known targets in a seeded test area.

The test of the ORAGS-Arrowhead total magnetic field array demonstrated a significant reduction in ambient noise in the two sensors located 2.6 meters from the centerline of the helicopter without compromising the efficiency of the aerodynamics or the quality of the data from the other sensors. In the presence of the high noise environment of the helicopter, relative noise levels between sensors were used to demonstrate this reduction. The conclusion is that the

new sensor positions show a clear reduction in rotor noise relative to the previous array configuration.

In summary, all system components in both airborne systems performed as anticipated. The noise at the inboard positions 2.6m from the centerline of the helicopter is somewhat higher than the noise levels of the other magnetometers, but is reduced over inboard magnetometers from the ORAGS-Hammerhead system. Flight performance and maneuverability were excellent with no ballast required.

3.6 Testing and Evaluation Plan

3.6.1 Demonstration Set-Up and Start-Up

Mobilization involved packing and transporting all system components by trailer to Martin State Airport near Baltimore MD and installing them on a Bell 206L Long Ranger helicopter. Calibration and compensation flights were conducted and results evaluated. The eight cesium magnetometers, GPS systems (positioning and attitude), fluxgate magnetometers, data recording console, and laser altimeter were tested to ensure proper operation and performance. The Mission Plan was read and signed by all project participants to assure safe operation of all systems.

3.6.2 Period of Operation

Mobilization of the geophysical crew from Oak Ridge, Tennessee began on July 19, 2002. One day travel was required to transport geophysical equipment from Oak Ridge to Baltimore, MD. The helicopter crew mobilized from Toronto, Canada on July 19 and arrived in Baltimore the same day. Installation of the Arrowhead total magnetic field system began the morning of July 21. No calibration site set-up was necessary, as ordnance and non-ordnance items had already been emplaced by the APG staff. Compensation flights and test flights were conducted on July 22, and total field data were acquired at the four sites during the period of July 22- 26, 2002. Data were acquired with the vertical gradient system from July 26-28. The system components were de-installed and the crew demobilized on July 29.

3.6.3 Area Characterized

A total of four sites were surveyed, along with a test area seeded with buried UXO items. All four sites encompassed known bombing or artillery targets. The areas surveyed at these sites are: Dewatering Ponds (DP, 107 acres / 43 hectares), the Mine, Grenade, and Direct-Fire weapons range (MGD, 124 acres/ 50 hectares), Active Recovery Field (ARF, 102 acres/ 41 hectares) and the Airfield site (AF, 14 acres/ 5.7 hectares). The total area surveyed by the total field system is thus 348 acres (141hectares). At each site, 100 percent coverage of the target area was attained using 12-m flight line spacing.

3.6.4 Residuals Handling

This section does not apply to this report.

3.6.5 Operating Parameters for the Technology

The ORAGS-Arrowhead system is designed for daylight operations only. Lines were flown in a generally east-west or north-south pattern depending on local logistics and weather conditions with a nominal 12m flight line spacing for the high density survey coverage. Binary data from the eight magnetometers was recorded on the console at a rate of 1200 samples per second. A typical survey speed for the system is 70 km/hr. However, the small size of the areas surveyed at APG precluded this production speed, and survey speeds of 40 km/hr were more typical. Average survey height for the four areas ranged from 1.5 to 3.9m. In areas where background magnetic susceptibility and variation is small, vegetation height low, and topographic change gradual, the system can be expected to detect anomalies as small as 2 nT, and ferrous masses as small as 2 kg UXO fragments. These thresholds can be expected to increase as any of the aforementioned variables increase.

3.6.6 Experimental Design

The tests conducted with the ORAGS-Arrowhead total magnetic field system are summarized in Table 3.2.

Table 3.2 - Field Tests with ORAGS-Arrowhead Total Magnetic Field System

Test ID	Description	Parameters	Sites
Standard configuration	Test overall system performance (aerodynamics, noise, compensation, positioning, orientation, detection)	Alt = ALASA at each of the four APG sites. Alt = 1.5m at Calibration Grid.	Full coverage of four APG sites: ARF, MGD, DP, and AF including the Calibration Grid.

Data quality objectives (DQOs) to be used for this technology demonstration focused on prior-generation airborne results as the baseline performance condition, as well as previous MTADS demonstration data. Analysis of prior-collected airborne data by the HM-3, shown in Figure 2.3, yielded preliminary results of 89% ordnance with 6% false positives (Doll et al., 1999). Analysis by the Institute for Defense Analyses (IDA) of the same ORNL data sets yielded slightly different results (78% to 83% ordnance, 17% to 24% false positives).

Subsequent airborne surveys at BBR, Shumaker Naval Ammunition Depot and Rocket Test Range, Nomans Land Island, and New Boston Air Force Station yielded results consistent with the previous surveys at BBR. One difference is that positional accuracy at the reference point on the aircraft has improved from approximately 2m in earlier tests to less than 1m in this test. This results from inclusion of post-processed (rather than real-time) differential corrections to the GPS data.

Given the various considerations associated with both the interpretation of airborne geophysical survey data and the calculations of the various performance parameters, DQOs for the demonstration of the fourth-generation total field system approached or met the current performance parameters. ORNL expected the ORAGS-Arrowhead total field system to provide detection in the vicinity of 90% ordnance with 5% to 7% false positives. The methodology used to acquire the airborne data are as described in previous sections of this document with a variety of altitudes flown. All surveys conducted with the Arrowhead total field system were performed as high-density surveys with line spacing established to account for sensor positions such that no gaps or voids exist in any data set, except where planned. Positioning accuracy for the anomalies detected were just under 100 cm.

Data processing procedures

The 1200 Hz raw data were desampled in the signal processing stage to a 120 Hz recording rate. All other raw data were recorded at a 120 Hz sample rate. Data were converted to an ASCII format and imported into a Geosoft format database for processing. With the exception of the differential GPS post-processing, all data processing was conducted using the Geosoft software suite and proprietary ORNL algorithms and filters. The quality control, positioning, and magnetic data processing procedures (steps a-i) are described below.

Quality Control

All data were examined in the field to ensure sufficient data quality for final processing. The adequacy of the compensation data, heading corrections, time lags, orientation calibration, overall performance and noise levels, and data format compatibility were all confirmed during data processing. During survey operations, flight lines were plotted to verify full coverage of the area. Missing lines or areas where data were not captured were reacquired. Data were also examined for high noise levels, data drop outs, significant diurnal activity, or other unacceptable conditions. Lines flown, but deemed to be unacceptable for quality reasons, were re-flown.

Positioning

During flight, the pilot was guided by an on-board navigation system that used real-time satellite-based DGPS positions. This provided sufficient accuracy for data collection (approximately 1m), but was inadequate for final data positioning. To increase the accuracy of the final data positioning, a base station GPS was established at geodetic base survey marker MARTAIR AZ MK JV6476 (NAD83 39° 19’ 57.88957” N 76° 25’ 38.50226” W NAVD88 6.311m). Raw data in the aircraft and on the ground were collected. Differential corrections were post-processed to provide increased accuracy in the final data positioning. The final

latitude and longitude data were projected onto an orthogonal grid using the North American Datum 1983 (NAD 83) UTM Zone 18N. Vertical positioning was monitored by laser altimeter with an accuracy of 2cm. No filtering was required of these data, although occasional drop-outs were removed.

Magnetic data processing procedure

The magnetic data were subjected to several stages of geophysical processing. These stages included correction for time lags, removal of sensor dropouts, compensation for dynamic helicopter effects, removal of diurnal variation, correction for sensor heading error, array balancing, and removal of helicopter rotor noise. The calculation of the magnetic analytic signal was derived from the corrected residual magnetic total field data.

(a) Time Lag Correction

There is a lag between the time the sensor makes a measurement and the time it is time stamped and recorded. This applies to both the magnetometer and the GPS. Accurate positioning requires a correction for this lag. Time lags between the magnetometers, fluxgate magnetometer, and GPS signals were measured by a proprietary ORAGS firmware utility. This utility sends a single pulse that is visible in the data streams of all three instruments. This lag was corrected in all data streams before processing.

(b) Sensor Dropouts

Cesium vapor magnetometers have a preferred orientation to the Earth's magnetic field. As a result of the motion of the aircraft, the sensor dead zones can occasionally align with the Earth's field. In this event, the readings drop out, usually from an average of 53,000 nT to 0 nT. This usually only occurs during turn-around between lines, and rarely during actual data acquisition. All dropouts were removed manually before processing.

(c) Aircraft Compensation

The presence of the helicopter in close proximity to the magnetic sensors results in considerable deviation in the readings, and generally requires some form of compensation. The orientation of the aircraft with respect to the sensors and the motion of the aircraft through the earth's magnetic field are also contributing factors. A special calibration flight is performed to record the information necessary to remove these effects. The maneuver consisted of a square or rectangular-shaped flight path at high altitude to gain information in each of the cardinal directions. During this procedure, the pitch, roll and yaw of the aircraft were varied. This provided a complete picture of the effects of the aircraft at all headings in all orientations. The entire maneuver was conducted twice for comparison. The information was used to calculate coefficients for a 19-term polynomial for each sensor. The fluxgate data were used as the baseline reference channel for orientation. The polynomial is applied post flight to the raw data, and the results are generally referred to as the compensated data. This data is used in the development of the analytic signal maps presented in this report.

(d) Magnetic Diurnal Variations
The earth's magnetic field changes constantly over the course of the day. This means that magnetic measurements include a randomly drifting background level. A base station sensor was established near the GPS base station monument at Martin State Airport to monitor and record this variation every five seconds. The recorded data are normally subtracted directly from the airborne data. The time stamps on the airborne and ground units were synchronized to GPS time. The diurnal activity recorded at the base station was extremely quiet. In general, the low frequency diurnal variations were less than 5nT per survey line. Processing included defaulting repeated values and linearly interpolating between the remaining points.

(e) Heading Corrections
Cesium vapor magnetometers are susceptible to heading errors. The result is that one sensor will give different readings when rotated about a stationary point. This error is usually less than 0.2 nT. Heading corrections were applied to adjust readings for this effect.

(f) Array Balancing
These magnetic sensors also provide a lower degree of absolute accuracy than relative accuracy. Different sensors in identical situations will measure the same relative change of 1 nT, but they may differ in their actual measured value, such as whether the change was from 50,000 to 50,001 nT or from 50,100 to 50,101 nT. After individual sensors were heading-corrected to a uniform background reading, the background level of each sensor was corrected or balanced to match the others across the entire airborne array.

(g) Regional Removal
Deep-seated, large scale background geology and some cultural features which contribute to the local regional magnetic field were removed using a combination of filtering and splining techniques. The output is a residual magnetic total field. This process also removed all diurnal, heading and balancing effects.

(h) Rotor Noise
The aircraft rotor spins at a constant rate of approximately 400 rpm. This introduces noise to the magnetic readings at a frequency of approximately 6.6 Hz. Harmonics at multiples of this base are also observable, but are much smaller. This frequency is usually higher than the spatial frequency created by near surface metallic objects. This effect has been removed with a low-pass frequency filter.

(i) Analytic Signal
The data resulting from this survey are presented in the form of analytic signal. The square root of the sum of the squares of the three orthogonal magnetic gradients is the total gradient or analytic signal. It represents the maximum rate of change of the magnetic field in any direction (i.e. a measure of how much the readings would change by moving a small amount in any direction such as left-right, forward-backward, or up-down). This parameter was calculated from the gridded residual total field data.

There are some advantages to using the analytic signal. For small objects, it is somewhat more straightforward to interpret visually than total field data. Total field measurements typically display a dipolar response signature to small, compact sources, having both a positive and negative deviation from the background. The actual source location is a point between the two peaks, as determined by the magnetic latitude of the site and the properties of the source itself. Analytic signal is more symmetric about the target, is always a positive value and has less dependence on magnetic latitude. Analytic signal maps present anomalies as low intensity to high intensity shapes.

3.6.7 Sampling Plan

This section does not apply to this report.

3.6.8 Demobilization

De-installation was carried out on July 29. Booms were dismounted from the helicopter frame and the magnetometers and GPS instrumentation were disconnected and packed in shipping containers. The containers were placed in a trailer and returned to Oak Ridge, Tennessee.

4.0 Performance Assessment

4.1 Performance Criteria

Demonstration effectiveness is determined directly from comparisons of the processed/analyzed results from the demonstration surveys and the results of previous airborne and ground-based surveys. These comparisons include both the quantitative and qualitative items described in this section. Demonstration success is determined as the successful acquisition of airborne geophysical data (without any aviation incident or airborne system failure) and meeting the baseline requirements for system performance as established previously in this document (Section 3.1). Methods utilized by ORNL on both current and past airborne acquisitions to ensure airborne survey success include daily QA/QC checks on all system parameters (e.g. GPS, magnetometer operation, data recording, system compensation measurements, etc.) in the acquired data sets, a series of compensation flights at the beginning of each survey, continual inspection of all system hardware and software ensuring optimal performance during the data acquisition phase, and review of data upon completion of each processing phase.

Several factors associated with data acquisition cannot be strictly controlled, such as aircraft altitude and attitude. Altitude can be recorded and will enter into the data analysis and comparisons with previous results. The aircraft attitude measuring system provides a documented database that cannot be directly compared with previous surveys when this system was not available. The consistent and scientific evaluation of performance is accomplished by

using identical or parallel (where parameters are dataset dependent) processing methods with identical software to produce a final map, and following consistent procedures in interpretation when comparing new and existing datasets from the test sites.

Data processing involves several steps, including GPS post-processing, compensation, spike removal, removal of magnetic diurnal variations, time lag correction, heading correction, filtering, gradient calculations, and gridding. Each step is performed in the same manner on data acquired with sequential generations of system at the same sites, to provide a basis for comparing the performance of the systems. The processing procedures have been selected and developed from experience with similar data over a span of more than five years for optimal sensitivity to UXO.

Data quality objectives, as described in Section 3.6.6 (Experimental Design), were used for this demonstration. Surveys over the previously described test areas were conducted as described in Section 3.6. Data collection occurred at flight altitudes over the various test areas and configurations as described in Section 3.6.6. Data confirmation was in accordance with the processes previously described.

Table 4.1 identifies the expected performance criteria for this demonstration, complete with expected/desired values (quantitative) and/or definitions and descriptions (qualitative). This table also identifies expected performance for each of the technologies present in this demonstration.

Table 4.1: Performance Criteria

Performance Criteria	**Expected Performance Metric (Pre-demo)**	**Performance Confirmation Method**	**Actual Performance (Post-demo)**
Primary Criteria (Performance Objectives) – Quantitative			
System Performance (total field system)	Ordnance detection – greater than 90%	Comparison to prior collected airborne and ground-based data	Ranged between 11% and 98%, depending on search radius and site acquisition conditions (see Tables 4.4-4.7).

System Performance (total field system)	False positives – less than or equal to 6%	Can't be determined from available validation data.	
System Performance (total field system)	Data acquisition rate – greater than or equal to 40 acres per hour	Comparison to prior ORNL-conducted airborne surveys	91 acres/hr averaged over APG sites
System Performance (total field system)	Detection threshold (sensitivity)	Comparison to prior collected ground-based geophysical data	Variable, dependent upon altitude
System Performance (total field system)	Anomaly positional accuracy	Comparison to known benchmarks and known (documented) anomalies at the test site locations	Less than 1m (see Tables 4, 5, and 6), varying with search radius.
Primary Criteria (Performance Objectives) – Qualitative			
Process Waste	None	Observations	No process waste.
Factors Affecting Technology	Helicopter geophysical noise	Comparison to expected noise levels based on prior geophysical measurements around the helicopter	Noise higher than in previous surveys.
Factors Affecting Technology	Helicopter geophysical noise	Comparison of sensor compensation measurements against prior compensation values	Higher FOM than in previous surveys.
Factors Affecting Technology	Helicopter movement	Record constellation changes and use during positioning accuracy determination	Recorded.
Secondary Criteria (Performance Objectives) – Quantitative			
Hazardous Materials	Some live ordnance expected	Observations and documentation during excavations	UXO-related materials excavated were either live ordnance or UXO fragments

Secondary Criteria (Performance Objectives) – Qualitative			
Reliability	No system or component failures	Observations and documentation	No components failed during the total field surveys
Ease of Use	Pilot “comfort” when flying with the system installed	Observations and documentation	Pilot states that he feels at ease flying the system under normal wind conditions
Ease of Use	No ballast required	Observations and documentation	Engineer declared the system balanced without need for ballast
Safety	Conformance with all FAA requirements and requirements as documented in the Mission Plan	Observations and documentation	System met all FAA flightworthiness requirements
Versatility	Cultural feature detection and mapping	No basis for assessment at this site.	
Maintenance	System mount points, hardware, and component inspection	Observations and documentation	Minimal wear and tear.

4.2 Performance Confirmation Methods

Accurate estimation of two of the system performance criteria, i.e. ordnance detection and false positives, are dependent largely on the method of post-survey excavation used. For the APG survey, 315 excavations were conducted by APG staff under the guidance of the ESTCP Program Office, including the ten items at the test grid, 234 measurements at ARF, and 71 measurements at AF.

4.3 Data Analysis, Interpretation, and Evaluation

The ORAGS-Arrowhead magnetometer system does not distinguish within the numerous features mapped between UXO and ferrous scrap without interpretation. The total field and analytic signal maps provided in this report depict bombing targets (areas of high ordnance density), infrastructure (fences or larger items or areas of ferrous debris associated with human activity), and potential UXO items (discrete sources). Those responses, interpreted as potential UXO, will likely also include smaller pieces of ferrous debris. Additional analysis and interpretation of the survey results are included in this final project report.

Positional accuracy

We estimated positional accuracy by comparison of predicted dig locations, chosen from the peak value of the analytic signal anomaly or by inversion using the DAS code, with actual position of items, as reported by ESTCP. Mean positional errors were determined for three search radii, and for three detection algorithms. These are tabulated in Tables 4.5, 4.6, and 4.7. The positioning errors range from 0.43 to 0.87m, depending on the search radius and detection algorithm.

Altitude

Survey altitude varies with topography, surface conditions and flight conditions along each line. The database will also contain data points at altitudes too high for standard UXO detection during turnarounds or other maneuvers. In order to capture representative altitudes for each area, we have removed all points where altitude exceeded 10m. Average altitudes were then calculated from the remaining data points.

Calibration Grid

A test grid or calibration site was established by APG staff to verify the system response to expected UXO items under local geologic conditions. Two parallel lines of UXO with about 20m spacing between ordnance items was prepared by APG staff. The list of seeded items is presented in Table 4.2. The area was established on a topographic flat region near area AF. The location of the grid was chosen based on suitability of the topography and absence of evidence of metallic debris. Results of the airborne magnetic survey are shown in Figures 4.1 and 4.2. These showed low levels of ferrous debris over much of the grid and a very large anomaly extending across the center of the eastern row of targets.

Table 4.2 Description of emplaced items at APG Calibration Grid

ID	Description	Orientation
1	60-mm	EW
2	60-mm	NS
3	81-mm	EW
4	81-mm	NS
5	2.75	EW
6	2.75	NS
7	105-mm	EW
8	105-mm	NS
9	155-mm	EW
10	155-mm	NS

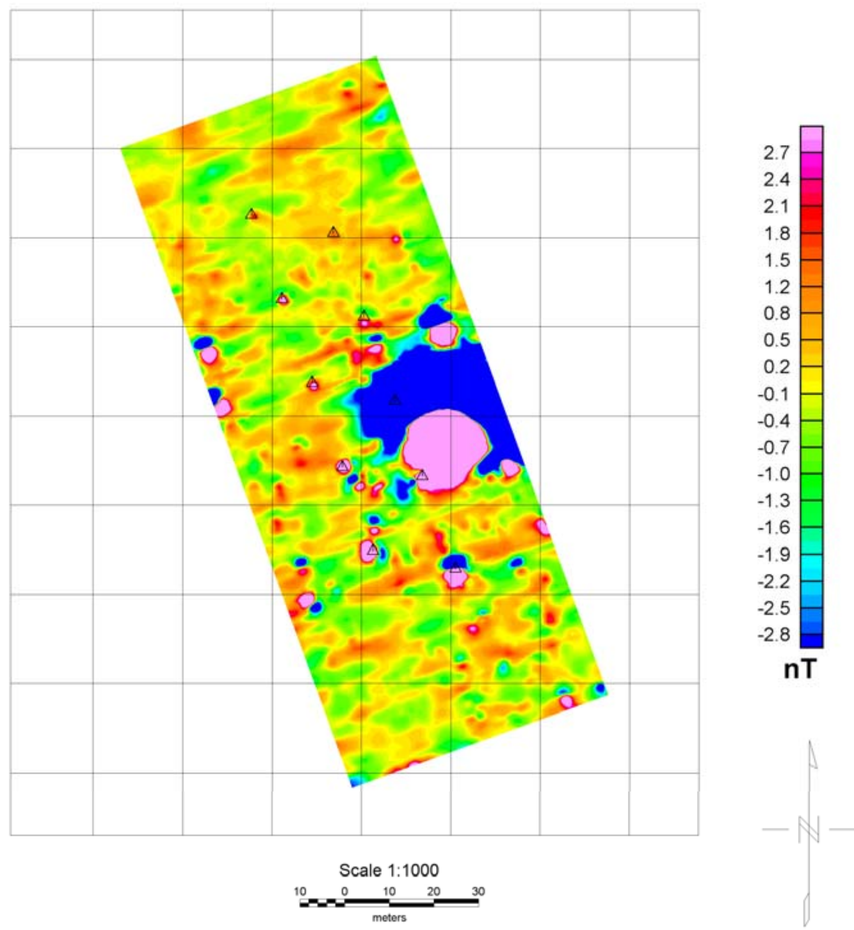


Figure 4.1 ORAGS-Arrowhead total magnetic field data over APG Calibration Grid. Nominal survey height: 1m.

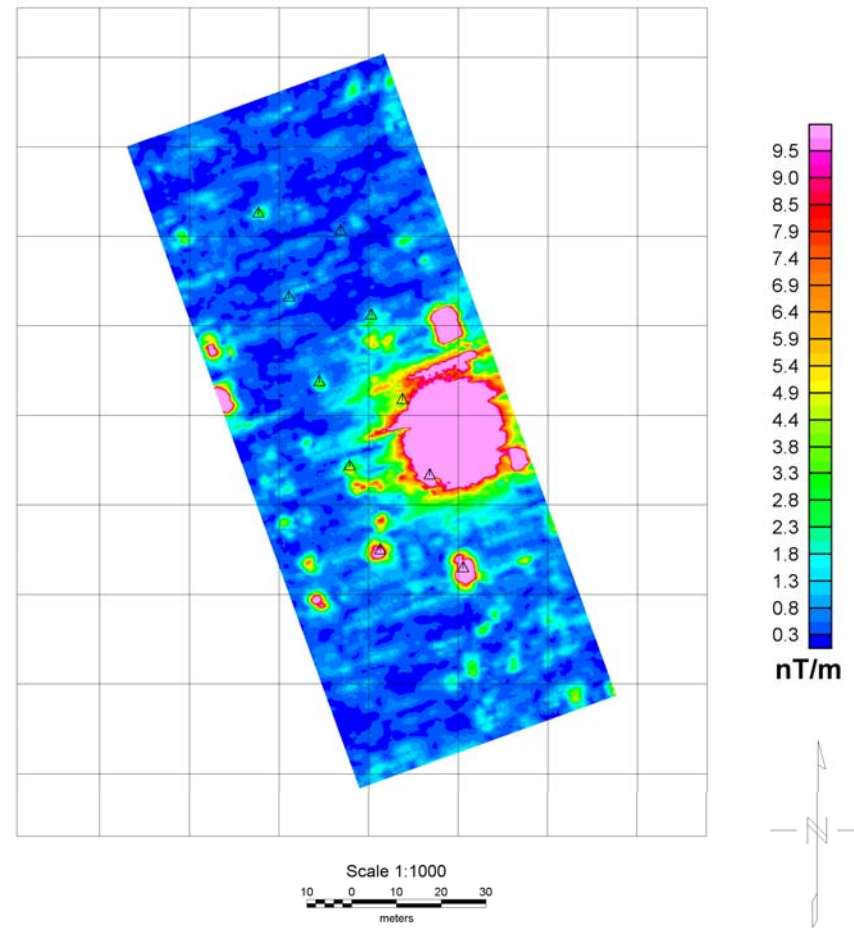


Figure 4.2 ORAGS-Arrowhead analytic signal map for APG Calibration Grid. Nominal survey height: 1m.

Airfield site (AF)
Lines were flown in an east-west direction with a 12m flight line separation. Survey heights over the entire area ranged from .83 m to 5.88 m and averaged 1.48 m. Figures 4.3 and 4.4 show anomaly maps of the total magnetic field and analytic signal. The average survey speed along line in AF was 10.9 m/s (39 km/hr), and the average coverage rate, including turnaround time, was 78 acres/hr or 32 ha/hr.

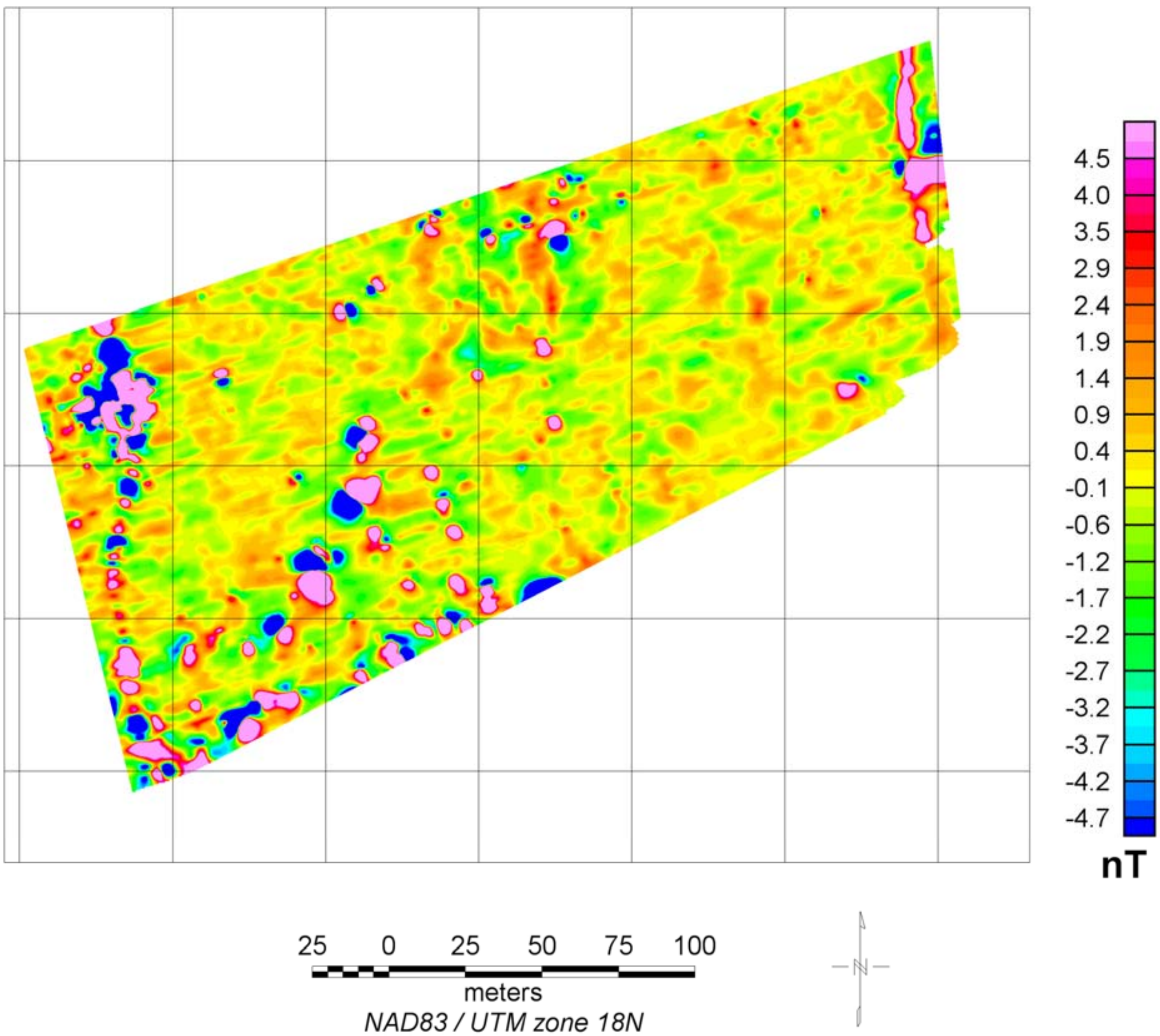


Figure 4.3 Total magnetic field residual anomaly map for the Airfield site.

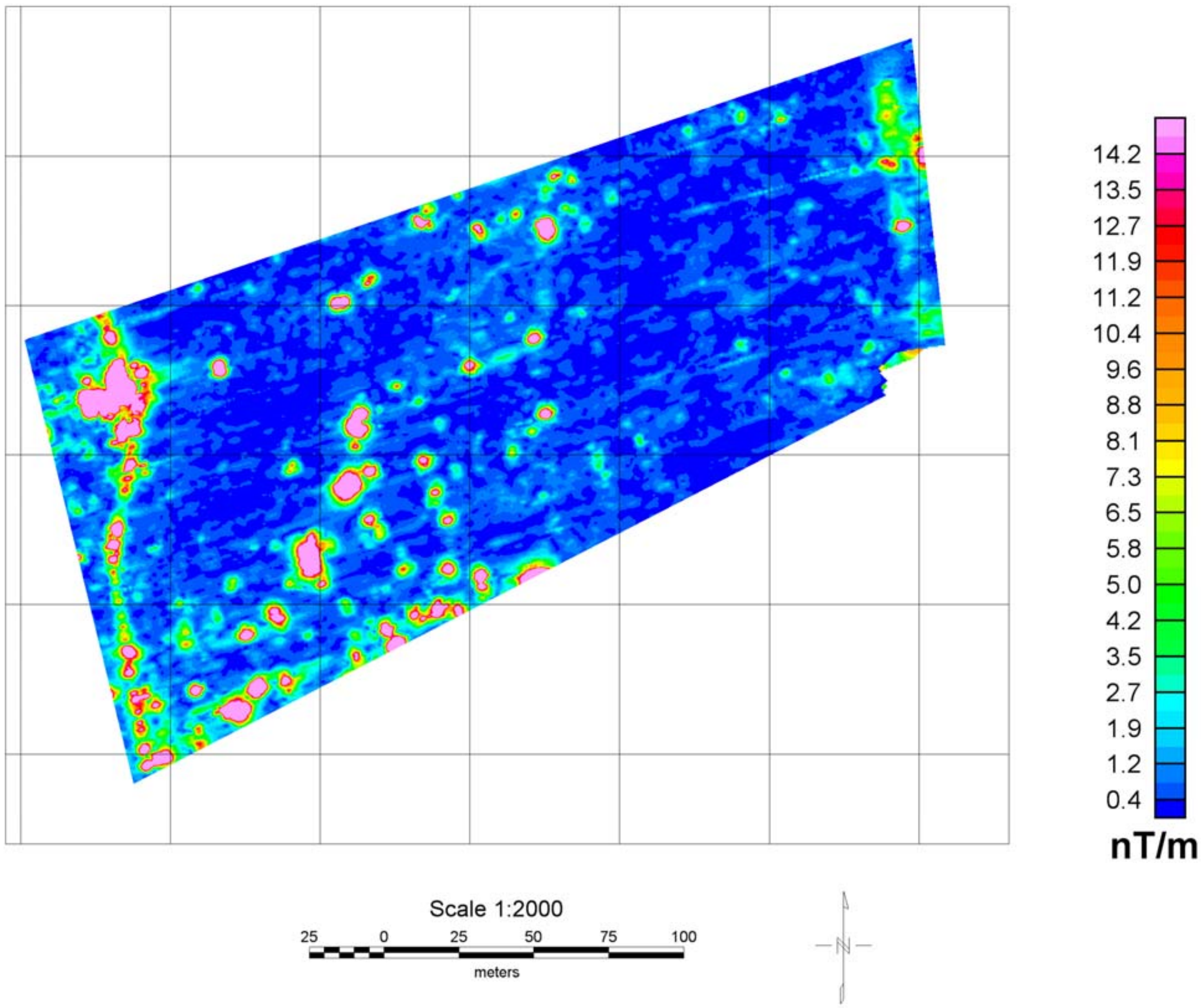


Figure 4.4 Analytic signal anomaly map for the Airfield site.

ARF Site

Lines were flown in a northeast-southwest direction with a 12m flight line separation. Total magnetic field and analytic signal anomaly maps are shown in Figures 4.5 and 4.6, respectively. Survey heights ranged from 0.23 to 8.44m and average survey height over the area was 2.07 m. Average survey speed along line in Area B was 9.5 m/s (34 km/h), and the average coverage rate, including turnaround time, was 70 acres/hr (28 ha/hr).

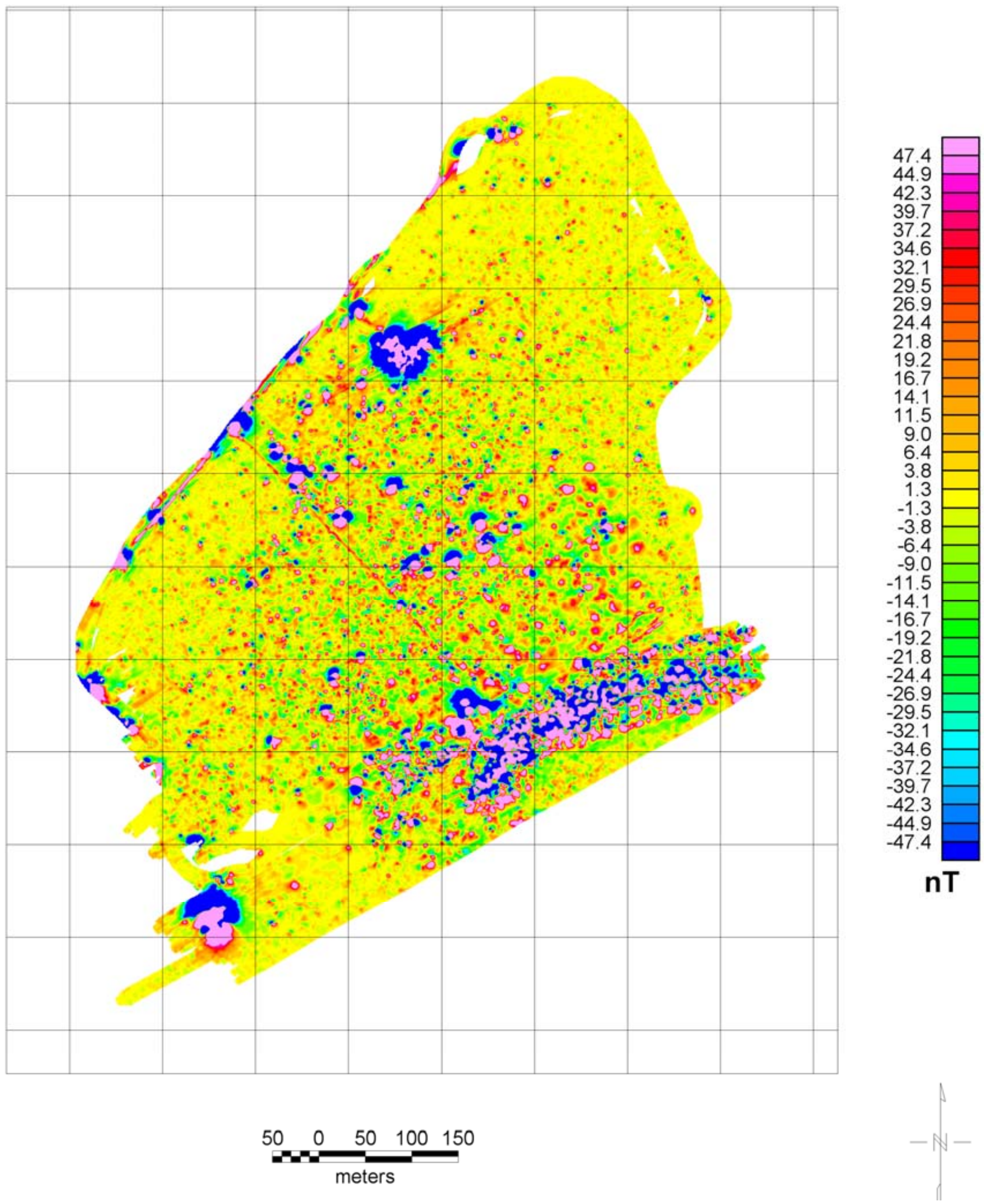


Figure 4.5 Total magnetic field residual anomaly map of the ARF site.

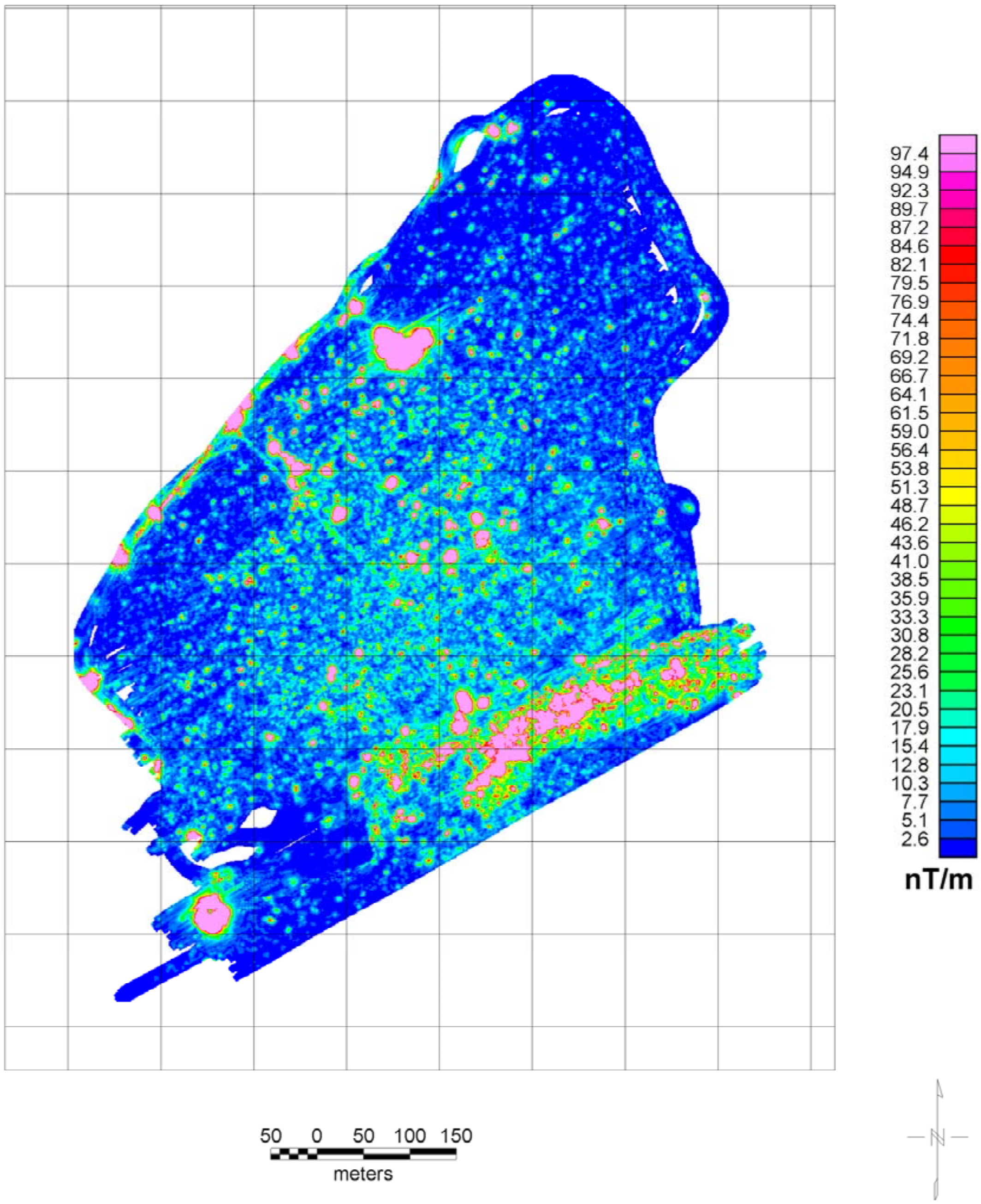


Figure 4.6. Analytic signal anomaly map of the ARF site.

Mine, Grenade, and Direct-fire Weapons Range

Lines at the MGD site were flown northwest-southeast using 12m flight line spacing. Total magnetic field and analytic signal maps are shown in Figures 4.7 and 4.8, respectively. The along line survey height ranged from 0.46 m to 10 m and averaged 2.93 m. The average survey speed along line was 12.9 m/s (46.5km/hr), and the average coverage rate, including turnarounds, was 112 acres/hr (45 ha/hr).

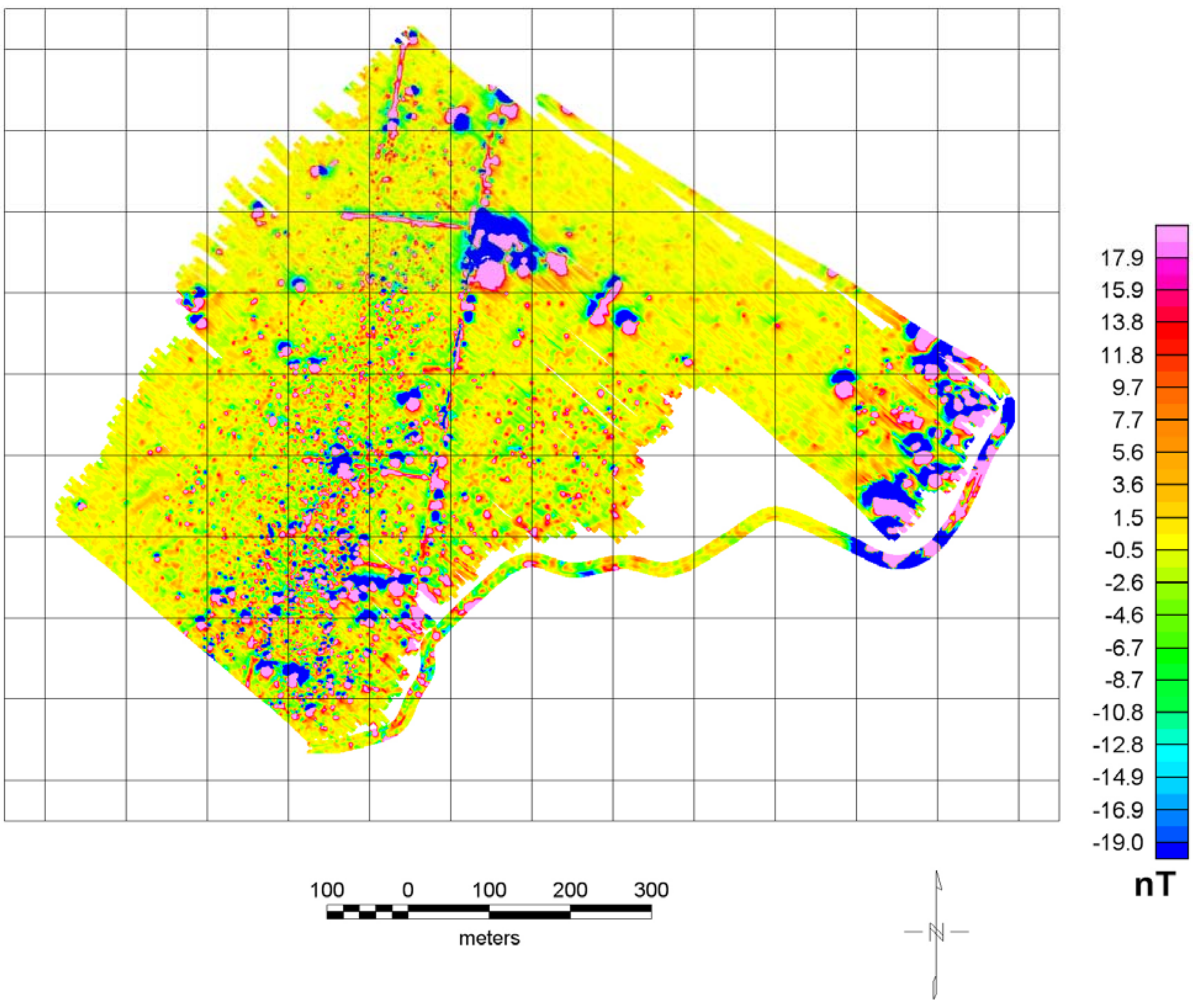


Figure 4.7 Total field anomaly map, MGD site.

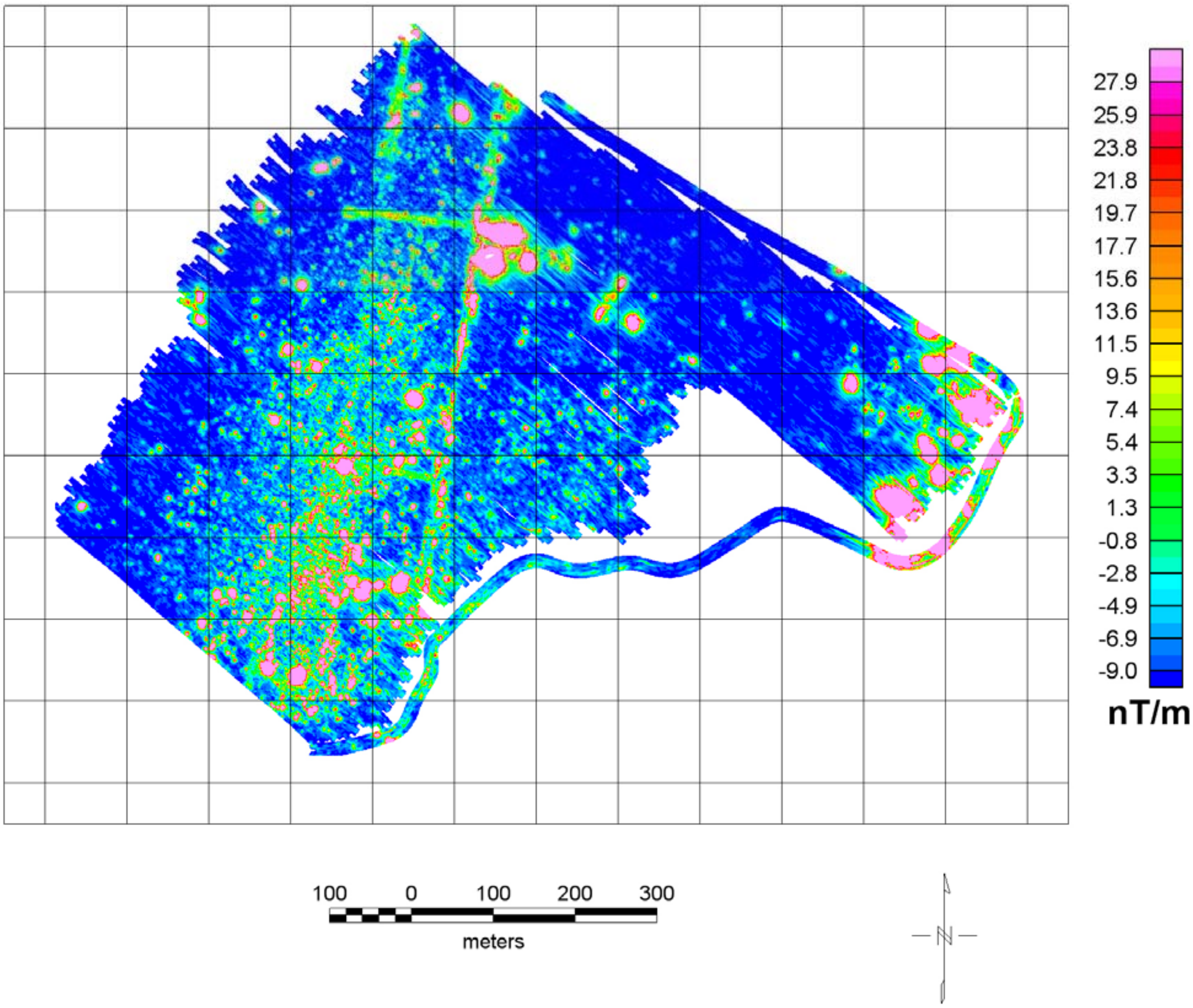


Figure 4.8 Analytic signal anomaly map, MGD site.

Dewatering Ponds Site

Lines at the DP site were flown east-west, with 12m flight line spacing. Total magnetic field and analytic signal maps are shown in Figures 4.9 and 4.10, respectively. The along line survey height ranged from 0.57 m to 10 m and averaged 3.86 m. The average survey speed along line at DP was 8.5 m/s (31 km/hr), and the average coverage rate, including turnarounds, was 102 acres/hr (41 ha/hr).

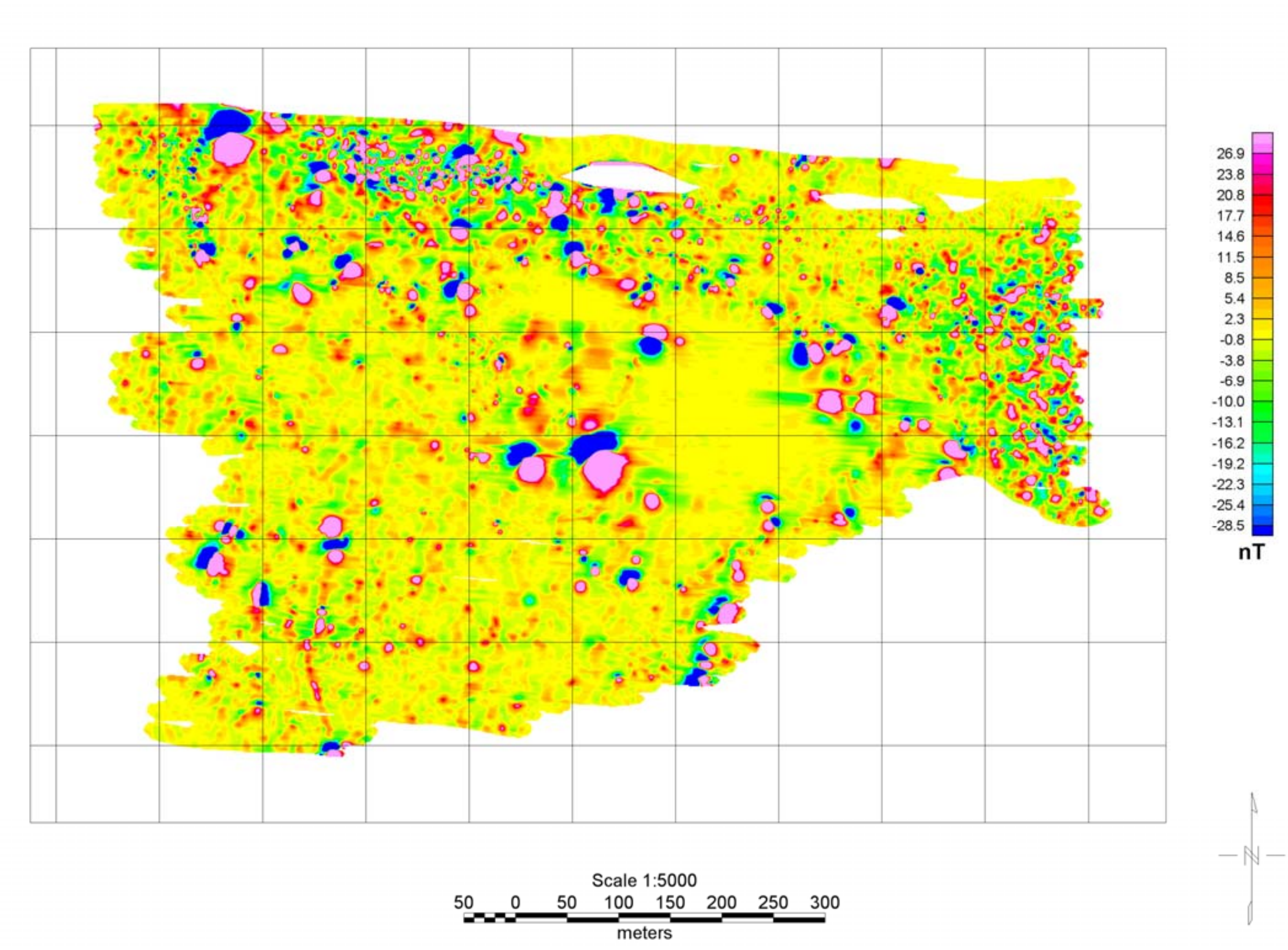


Figure 4.9 Total magnetic field anomaly map of the DP site

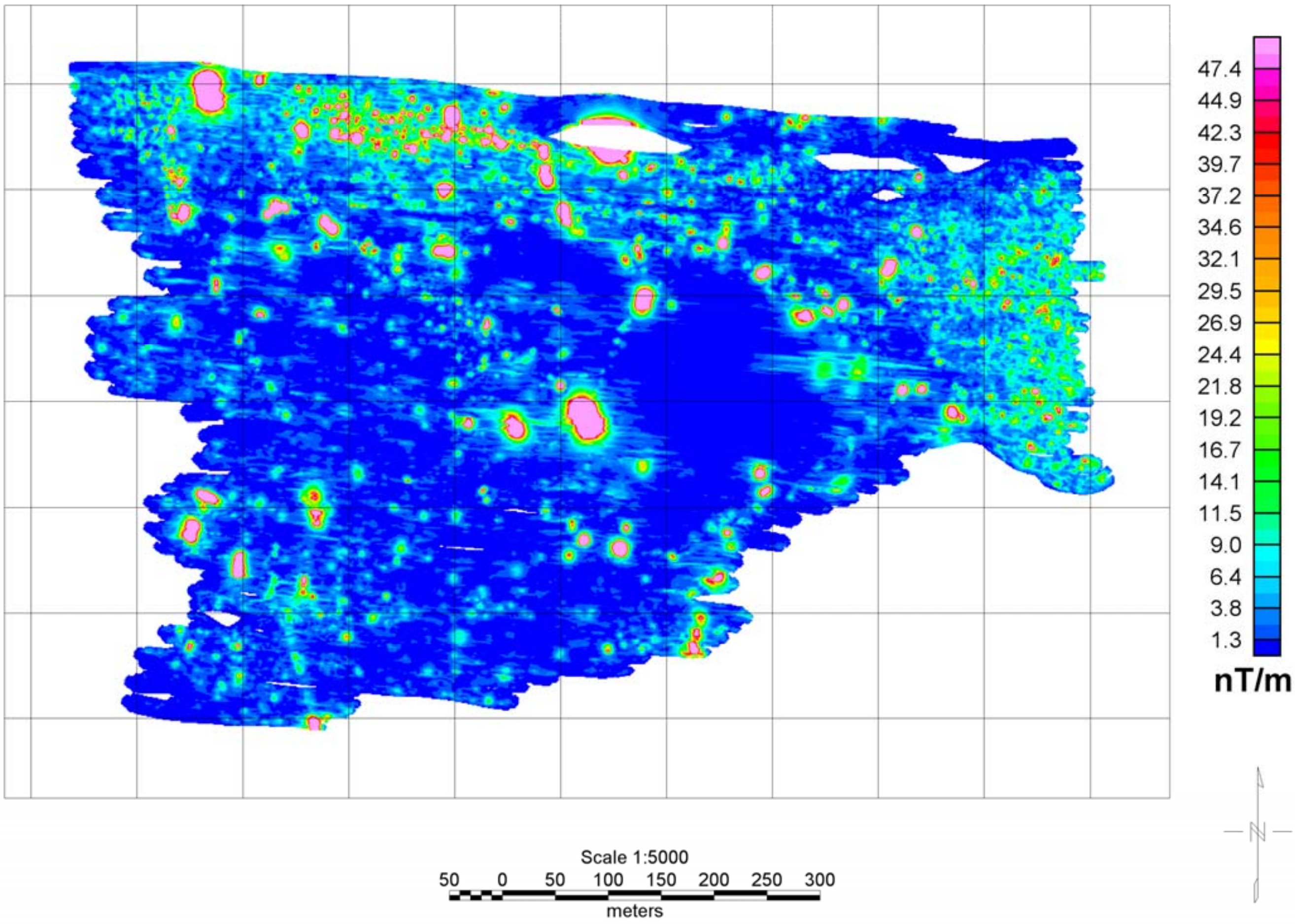


Figure 4.10 Analytic signal map of the DP site.

Sensor noise levels
Sensors behaved as expected during the demonstration, but noise levels associated with the helicopter were higher than levels measured in other demonstration surveys. Figure 4.11 shows a 40 second portion of total magnetic field data acquired at altitude near APG. The effects of the rotor and blades have not been removed from the data in the top panel. Sensors 2 and 7, the two inboard sensors on the rear booms, have higher noise levels than either the outer rear sensors or the four forward sensors.

Inclusion of low frequency noise components would not properly represent the noise field of interest in this survey. Rather than de-mean the total field data for each sensor and calculating the standard deviation of noise over the full 40 second window, we calculated a rolling standard deviation with a moving 10sec window for the whole flight. The noise was determined as the average of all eight sensors over the 40 second window. This yielded raw data noise standard deviation of 1.70 nT, a compensated noise level of 1.48 nT, a residual noise value of 0.64 nT, and a filtered noise level of 0.27nT.

For low frequency compensation noise, the Figure of Merit (FOM) provides a measure of the residual aircraft signature after compensation. The FOM is calculated as the sum of the remaining peak-peak noise after correction in each of the twelve parts of the compensation flight.

$$FOM = \sum noise_{ij}$$

where noise = average residual peak-peak deflection,
and i = cardinal direction (N, S, E, W)
and j = maneuver (pitch, roll, yaw).

Perfect compensation would produce a FOM equal to 12x the system noise floor. For fixed wing operations, a typical compensation will produce a FOM of 1nT. Boom-mounted helicopter operations typically produce a total field FOM of 2-10nT. Compensated data at APG yield a FOM of 18.86 nT, well in excess of that which is normally observed.

Anomaly evaluation

Intrusive investigations were conducted at two sites at APG, ARF and AF. In addition, the ten seeded items from the calibration site were recovered. The full descriptions of dig results are presented in Appendix E. The breakdown of these excavations in terms of UXO, UXO fragments (“frag”), and non-ordnance items is given in Table 4.3. A total of 234 items were dug at ARF, including 64 seeded items. Of these 234 items 192 were selected by IDA for scoring. Results are broken into two parts, first the 192 earmarked anomalies are presented and an additional table of the omitted items by IDA is also presented. There were 71 intrusive investigations at AF, of which 52 were seeded items. Anomaly selection at these sites (apart from seeded items) was based on dig lists derived from the ORAGS-Arrowhead data and from a

second airborne system that was operated by the Naval Research Laboratory. Two dig lists were provided by our team, using two automated selection and prioritization procedures in development at ORNL – a univariate (UV) statistical procedure and a multivariate (MV) statistical procedure (Appendix A of this report; Beard et al., 2003). Anomalies were subsequently selected and prioritized by ORNL staff using the Naval Research Laboratory's DAS code. For each of the three analysis approaches (UV, MV, and DAS) anomalies were assigned a classification of 1 through 6 according to the following general categories: 1, most likely UXO; 2, probably UXO; 3, possibly UXO; 4, possibly scrap; 5, probably scrap; and 6, most likely scrap. No ground survey data were acquired, nor was a full validation (excavation of all anomalies within a selected area) conducted.

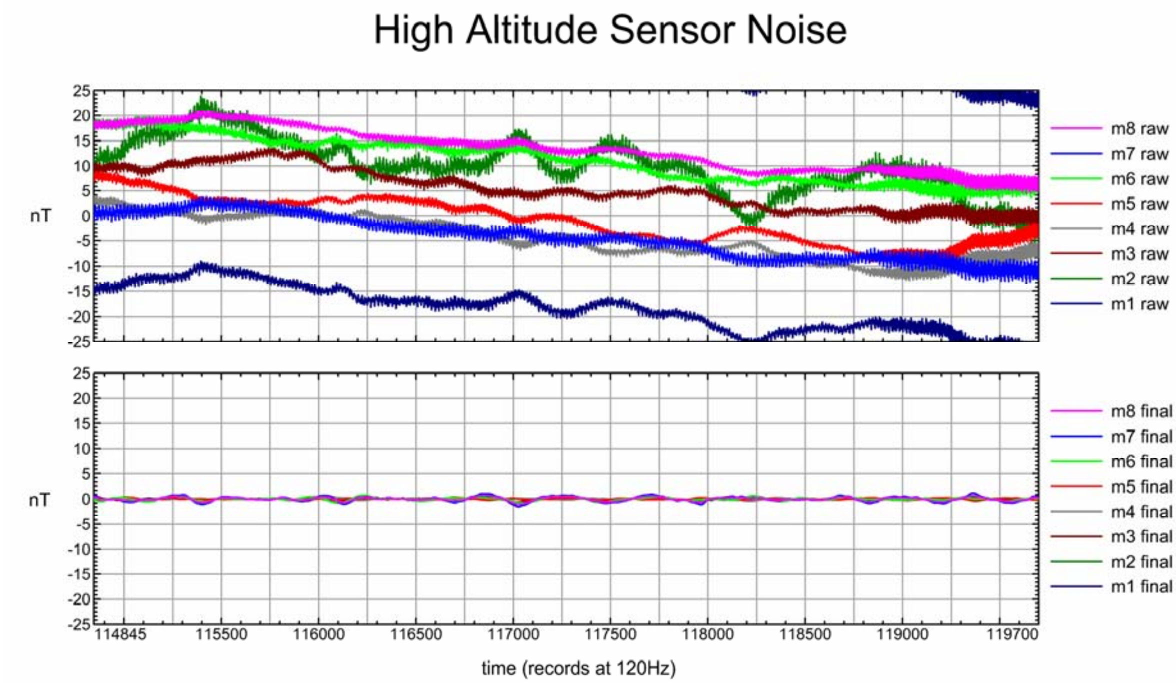


Figure 4.11 Forty second record of total magnetic field data from each of the eight acquired at altitude at APG. The effects of the helicopter blade and rotor have not yet been removed from the raw data. The final data (lower panel) are compensated and filtered for rotor noise.

Table 4.3. Intrusive dig summary for APG sites

Area	Class	Classification	Count
ARF	Dig	Clutter	78
ARF	Dig	Ordnance	50
ARF	Seed	Ordnance	64
Calibration Grid	Seed	Ordnance	47
AF	Calibration	Ordnance	10
AF	Seed	Ordnance	52

The dig results provide a basis for comparing the performance of the automated statistical methods with the established and more manually intensive DAS code. Because of the large number of anomalies detected in an airborne survey, we believe that automated or semi-automated methods will have an important role in assessing the large areas where UXO must be detected at DoD sites. The APG results also provide an initial data bank in which anomaly attributes and the related ordnance (or non-ordnance) items can be stored for development of improved statistical methods. This will lead to development and testing of improved statistical methods. Several parameters, including dig radius, must be considered in this process. Therefore, we have compiled results of the performance of the three selection and prioritization procedures (UV, MV, and DAS) for search radii of 1.0, 1.5, and 2m. These results are summarized in Table 4.4. They are broken down by ordnance type for each search radius in Tables 4.5, 4.6 and 4.7. For completeness, these tables include results with the ORAGS-VG vertical magnetic gradient system. This system is not discussed in this report, but is the subject of a separate ORNL report to ESTCP ("Final Report on 2002 Testing of Airborne Vertical Magnetic Gradiometer System", released in 2004). From the performance assessments at 1m, 1.5m, and 2m search radii, we see improved detection with increasing radius, as expected. We note that the coordinates used for excavation were based on aMTADS lists provided by the Naval Research Laboratory team rather than the ORNL picks. Actual locations used to determine positioning errors were those provided by APG. Compilation of validation results were the responsibility of IDA and APG. This analysis involved rejection of some of the intrusive items for reasons that are not known to us. For example, preliminary dig results for ARF showed 99 clutter items and 71 ordnance items. Final dig results included only 78 clutter items and 50 ordnance items.

Several observations may be made regarding these results:
1) Our efforts at prioritization and classification of anomalies were not effective at distinguishing between ordnance and clutter. This is not particularly surprising. First, this was our initial attempt at classifying anomalies. In the past, we had only provided anomaly lists, ranked according to the amplitude of the analytic signal peaks. Second, we had no capacity for comparing anomaly parameters to those in a library of representative anomalies. Our assessments were based on the items in the calibration site, which was intended to contain items that were representative of those at the survey sites, while in fact the survey sites contained a much greater diversity of ordnance types.

2) Performance in the double-blind part of the study (where anomalies were investigated based on anomaly lists) was considerably better than the performance over the seeded items. The reasons for this are not completely clear. Some of the difference may be explained by differences in survey heights. We found that many of the seeded items, particularly at the ARF site, were placed preferentially at boundaries of the study areas, or where conditions forced higher altitude acquisition. We investigated performance independently for those items where the altitude was less than 3m during acquisition. Altitude-linked assessment of the seeded items at ARF shows that average altitude of the ORAGS system over these items was 3.75m, nearly

twice the mean altitude over the site of 2.05 m. Of the 64 seeded items at ARF, only 24 were in an area where data were acquired at normal operating altitudes. Thirty-two were concentrated in a high-altitude patch near the edge of the grid in the southeast, and eight were acquired in a less-dense high-altitude patch in the southwest. This is illustrated in Figure 4.12. It shows the seed items superimposed on a map of aircraft altitude at the site. It appears that the helicopter pilot was at altitude over many of the excavated anomalies, perhaps due in part to premature ascent near the ends of lines. In Table 4.8, the ordnance category is extracted for each analysis technique for the ARF site, and performance is evaluated separately for those targets where flight altitude was less than 3m. Although the benefit of isolated anomalies where altitude was less than 3m is small for the DAS picks, there is a consistent improvement of about 10% in finds for the multivariate and univariate methods, for all search radii. Furthermore, if the collection of seed items did not fully represent the types of ordnance and scrap found in the field sites, this too could be expected to produce differences in seed versus field results. We do not have the information required to evaluate this possibility.

3) Better results were obtained for large ordnance than for smaller ordnance. Detection was consistently better for 105mm than for smaller ordnance types, particularly 60mm and 81mm. This is as expected. Many of the ordnance items at APG are too small to be suitable for airborne surveying at the altitudes deemed safe by our pilots.

4) Detection results improve with increased search radius. The accuracy of our anomaly positioning techniques was hindered by an attitude measurement system that was intermittent. Inadequate attitude data can easily lead to errors of several tenths of a meter in positioning. Our installation procedures for this system have subsequently improved, and alternative systems of attitude measurement are in evaluation.

5) Although the UV and MV anomaly prioritization and classification schemes generate considerably more anomalies than the DAS method, they also correctly detect a larger portion of the anomalies. Thus they generate a larger number of false positives, but may provide a more reliable basis for distinguishing concentrations of ordnance than manually intensive methods. This difference may favor the use of automated statistical methods over manually intensive methods where airborne systems are to be used for to identify concentrations of ordnance for wide-area assessment.

Table 4.4 Dig Results for 1m, 1.5m, and 2m search radius
Note: Classification "C" in column 4 implies clutter.

System	Area	Class	Classification	Found	Total Emplaced	1m Rate	Avg Err. (m)	Avg Prior
DAS	ARF	Dig	C	14	78	18%	0.48	3.36
DAS	ARF	Dig	Ordnance	9	50	18%	0.48	4.33
DAS	AF	Seed	Ordnance	27	64	42%	0.43	3.22
MV	ARF	Dig	C	68	78	87%	0.50	2.72
MV	ARF	Dig	Ordnance	43	50	86%	0.46	2.74
MV	ARF	Seed	Ordnance	7	64	11%	0.59	3.43
MV	AF	Calibration	Ordnance	6	10	60%	0.62	1.83
MV	AF	Seed	Ordnance	20	52	38%	0.56	3.35
UV	ARF	Dig	C	68	78	87%	0.50	3.26
UV	ARF	Dig	Ordnance	43	50	86%	0.46	2.95
UV	ARF	Seed	Ordnance	7	64	11%	0.59	3.71
UV	AF	Calibration	Ordnance	6	10	60%	0.62	1.50
UV	AF	Seed	Ordnance	20	52	38%	0.56	1.60
VG	AF	Seed	Ordnance	25	52	48%	0.63	1.80
System	Area	Class	Classification	Found	Total Emplaced	1.5m Rate	Avg Err (m)	Avg Prior
DAS	ARF	Dig	C	17	78	22%	0.60	3.47
DAS	ARF	Dig	Ordnance	11	50	22%	0.62	4.45
DAS	AF	Seed	Ordnance	28	64	44%	0.47	3.21
MV	ARF	Dig	C	76	78	97%	0.58	2.70
MV	ARF	Dig	Ordnance	47	50	94%	0.53	2.74
MV	ARF	Seed	Ordnance	9	64	14%	0.75	3.78
MV	AF	Calibration	Ordnance	8	10	80%	0.76	1.88
MV	AF	Seed	Ordnance	27	52	52%	0.72	3.15
UV	ARF	Dig	C	76	78	97%	0.58	3.22
UV	ARF	Dig	Ordnance	47	50	94%	0.53	2.87
UV	ARF	Seed	Ordnance	9	64	14%	0.75	3.89
UV	AF	Calibration	Ordnance	8	10	80%	0.76	1.63
UV	AF	Seed	Ordnance	27	52	52%	0.72	1.63
VG	AF	Seed	Ordnance	36	52	69%	0.81	1.97
System	Area	Class	Classification	Found	Total Emplaced	2.0m Rate	Avg Err (m)	Avg Prior
DAS	ARF	Dig	C	18	78	23%	0.67	3.39
DAS	ARF	Dig	Ordnance	12	50	24%	0.70	4.33
DAS	AF	Seed	Ordnance	29	64	45%	0.50	3.21
MV	ARF	Dig	C	77	78	99%	0.59	2.71

MV	ARF	Dig	Ordnance	49	50	98%	0.58	2.76
MV	ARF	Seed	Ordnance	11	64	17%	0.96	3.91
MV	AF	Calibration	Ordnance	9	10	90%	0.85	1.89
MV	AF	Seed	Ordnance	29	52	56%	0.80	3.10
UV	ARF	Dig	C	77	78	99%	0.59	3.21
UV	ARF	Dig	Ordnance	49	50	98%	0.58	2.84
UV	ARF	Seed	Ordnance	11	64	17%	0.96	3.82
UV	AF	Calibration	Ordnance	9	10	90%	0.85	2.00
UV	AF	Seed	Ordnance	29	52	56%	0.80	1.66
VG	AF	Seed	Ordnance	39	52	75%	0.87	1.97

Table 4.5 Dig Results for 1m search radius, broken down by ordnance type

System	Area	Class	Classification	Type	Found	Emplaced	Rate	Avg Err	Avg Priority
DAS	ARF	Dig	C	Frag	8	60	13%	0.44	2.75
DAS	ARF	Dig	C	Scrap	6	18	33%	0.54	4.17
DAS	ARF	Dig	Ordnance	105mm	1	1	100%	0.95	2.00
DAS	ARF	Dig	Ordnance	106mm	1	1	100%	0.39	6.00
DAS	ARF	Dig	Ordnance	120mm	1	4	25%	0.14	6.00
DAS	ARF	Dig	Ordnance	14in	1	1	100%	0.20	6.00
DAS	ARF	Dig	Ordnance	155mm	4	17	24%	0.50	4.25
DAS	ARF	Dig	Ordnance	175mm	1	1	100%	0.64	2.00
DAS	AF	Seed	Ordnance	105mm	19	28	68%	0.42	3.26
DAS	AF	Seed	Ordnance	60mm	1	3	33%	0.40	3.00
DAS	AF	Seed	Ordnance	81mm	7	21	33%	0.47	3.14
MV	ARF	Dig	C	Frag	51	60	85%	0.50	2.73
MV	ARF	Dig	C	Scrap	17	18	94%	0.50	2.71
MV	ARF	Dig	Ordnance	105mm	1	1	100%	0.80	1.00
MV	ARF	Dig	Ordnance	105mm - Partial	1	1	100%	0.04	4.00
MV	ARF	Dig	Ordnance	106mm	1	1	100%	0.09	4.00
MV	ARF	Dig	Ordnance	120mm	4	4	100%	0.38	3.25
MV	ARF	Dig	Ordnance	14in	1	1	100%	0.25	4.00
MV	ARF	Dig	Ordnance	155mm	15	17	88%	0.48	2.60
MV	ARF	Dig	Ordnance	175mm	1	1	100%	0.23	2.00
MV	ARF	Dig	Ordnance	2.75in Rocket	1	1	100%	0.72	3.00
MV	ARF	Dig	Ordnance	240mm	1	1	100%	0.49	3.00
MV	ARF	Dig	Ordnance	5in	2	2	100%	0.28	3.00

MV	ARF	Dig	Ordnance	6in	1	1	100%	0.24	2.00
MV	ARF	Dig	Ordnance	75mm	3	3	100%	0.55	3.00
MV	ARF	Dig	Ordnance	8in	3	3	100%	0.62	3.33
MV	ARF	Dig	Ordnance	90mm	6	10	60%	0.46	2.50
MV	ARF	Dig	Ordnance	90mm - Partial	1	2	50%	0.82	1.00
MV	ARF	Dig	Ordnance	Butterfly bomb	1	1	100%	0.54	2.00
MV	ARF	Seed	Ordnance	105mm	5	32	16%	0.70	3.60
MV	ARF	Seed	Ordnance	81mm	2	32	6%	0.31	3.00
MV	AF	Calib	Ordnance	105mm	2	2	100%	0.53	2.00
MV	AF	Calib	Ordnance	155mm	1	2	50%	0.61	2.00
MV	AF	Calib	Ordnance	2.75 in	1	2	50%	0.97	1.00
MV	AF	Calib	Ordnance	60mm	1	2	50%	0.67	2.00
MV	AF	Calib	Ordnance	81mm	1	2	50%	0.43	2.00
MV	AF	Seed	Ordnance	105mm	15	28	54%	0.60	3.40
MV	AF	Seed	Ordnance	60mm	1	3	33%	0.27	5.00
MV	AF	Seed	Ordnance	81mm	4	21	19%	0.48	2.75
UV	ARF	Dig	C	Frag	51	60	85%	0.50	3.37
UV	ARF	Dig	C	Scrap	17	18	94%	0.50	2.94
UV	ARF	Dig	Ordnance	105mm	1	1	100%	0.80	2.00
UV	ARF	Dig	Ordnance	105mm - Partial	1	1	100%	0.04	4.00
UV	ARF	Dig	Ordnance	106mm	1	1	100%	0.09	3.00
UV	ARF	Dig	Ordnance	120mm	4	4	100%	0.38	3.00
UV	ARF	Dig	Ordnance	14in	1	1	100%	0.25	4.00
UV	ARF	Dig	Ordnance	155mm	15	17	88%	0.48	2.87
UV	ARF	Dig	Ordnance	175mm	1	1	100%	0.23	3.00
UV	ARF	Dig	Ordnance	2.75in Rocket	1	1	100%	0.72	3.00
UV	ARF	Dig	Ordnance	240mm	1	1	100%	0.49	2.00
UV	ARF	Dig	Ordnance	5in	2	2	100%	0.28	3.50
UV	ARF	Dig	Ordnance	6in	1	1	100%	0.24	4.00
UV	ARF	Dig	Ordnance	75mm	3	3	100%	0.55	3.33
UV	ARF	Dig	Ordnance	8in	3	3	100%	0.62	2.67
UV	ARF	Dig	Ordnance	90mm	6	10	60%	0.46	3.00
UV	ARF	Dig	Ordnance	90mm - Partial	1	2	50%	0.82	2.00
UV	ARF	Dig	Ordnance	Butterfly bomb	1	1	100%	0.54	2.00
UV	ARF	Seed	Ordnance	105mm	5	32	16%	0.70	4.40
UV	ARF	Seed	Ordnance	81mm	2	32	6%	0.31	2.00

UV	AF	Calib	Ordnance	105mm	2	2	100%	0.53	2.00
UV	AF	Calib	Ordnance	155mm	1	2	50%	0.61	1.00
UV	AF	Calib	Ordnance	2.75 in	1	2	50%	0.97	1.00
UV	AF	Calib	Ordnance	60mm	1	2	50%	0.67	2.00
UV	AF	Calib	Ordnance	81mm	1	2	50%	0.43	1.00
UV	AF	Seed	Ordnance	105mm	15	28	54%	0.60	1.60
UV	AF	Seed	Ordnance	60mm	1	3	33%	0.27	2.00
UV	AF	Seed	Ordnance	81mm	4	21	19%	0.48	1.50
VG	AF	Seed	Ordnance	105mm	16	28	57%	0.58	1.81
VG	AF	Seed	Ordnance	60mm	2	3	67%	0.59	1.50
VG	AF	Seed	Ordnance	81mm	7	21	33%	0.77	1.86

Table 4.6 Dig Results for 1.5m search radius, broken down by ordnance type

System	Area	Class	Classification	Type	Found	Emplaced	Rate	Avg Err	Avg Prior
DAS	ARF	Dig	C	Frag	9	60	15%	0.51	3.11
DAS	ARF	Dig	C	Scrap	8	18	44%	0.70	3.88
DAS	ARF	Dig	Ordnance	105mm	1	1	100%	0.95	2.00
DAS	ARF	Dig	Ordnance	106mm	1	1	100%	0.39	6.00
DAS	ARF	Dig	Ordnance	120mm	1	4	25%	0.14	6.00
DAS	ARF	Dig	Ordnance	14in	1	1	100%	0.20	6.00
DAS	ARF	Dig	Ordnance	155mm	4	17	24%	0.50	4.25
DAS	ARF	Dig	Ordnance	175mm	1	1	100%	0.64	2.00
DAS	ARF	Dig	Ordnance	90mm - Partial	2	2	100%	1.25	5.00
DAS	AF	Seed	Ordnance	105mm	19	28	68%	0.42	3.26
DAS	AF	Seed	Ordnance	60mm	2	3	67%	0.91	3.00
DAS	AF	Seed	Ordnance	81mm	7	21	33%	0.47	3.14
MV	ARF	Dig	C	Frag	59	60	98%	0.60	2.69
MV	ARF	Dig	C	Scrap	17	18	94%	0.50	2.71
MV	ARF	Dig	Ordnance	105mm	1	1	100%	0.80	1.00
MV	ARF	Dig	Ordnance	105mm - Partial	1	1	100%	0.04	4.00
MV	ARF	Dig	Ordnance	106mm	1	1	100%	0.09	4.00
MV	ARF	Dig	Ordnance	120mm	4	4	100%	0.38	3.25
MV	ARF	Dig	Ordnance	14in	1	1	100%	0.25	4.00
MV	ARF	Dig	Ordnance	155mm	16	17	94%	0.53	2.63
MV	ARF	Dig	Ordnance	175mm	1	1	100%	0.23	2.00
MV	ARF	Dig	Ordnance	2.75in Rocket	1	1	100%	0.72	3.00
MV	ARF	Dig	Ordnance	240mm	1	1	100%	0.49	3.00

MV	ARF	Dig	Ordnance	5in	2	2	100%	0.28	3.00
MV	ARF	Dig	Ordnance	6in	1	1	100%	0.24	2.00
MV	ARF	Dig	Ordnance	75mm	3	3	100%	0.55	3.00
MV	ARF	Dig	Ordnance	8in	3	3	100%	0.62	3.33
MV	ARF	Dig	Ordnance	90mm	8	10	80%	0.64	2.75
MV	ARF	Dig	Ordnance	90mm - Partial	2	2	100%	1.12	1.00
MV	ARF	Dig	Ordnance	Butterfly bomb	1	1	100%	0.54	2.00
MV	ARF	Seed	Ordnance	105mm	5	32	16%	0.70	3.60
MV	ARF	Seed	Ordnance	81mm	4	32	13%	0.80	4.00
MV	AF	Calib	Ordnance	105mm	2	2	100%	0.53	2.00
MV	AF	Calib	Ordnance	155mm	2	2	100%	0.83	2.00
MV	AF	Calib	Ordnance	2.75 in	1	2	50%	0.97	1.00
MV	AF	Calib	Ordnance	60mm	1	2	50%	0.67	2.00
MV	AF	Calib	Ordnance	81mm	2	2	100%	0.87	2.00
MV	AF	Seed	Ordnance	105mm	21	28	75%	0.76	3.14
MV	AF	Seed	Ordnance	60mm	2	3	67%	0.74	4.00
MV	AF	Seed	Ordnance	81mm	4	21	19%	0.48	2.75
UV	ARF	Dig	C	Frag	59	60	98%	0.60	3.31
UV	ARF	Dig	C	Scrap	17	18	94%	0.50	2.94
UV	ARF	Dig	Ordnance	105mm	1	1	100%	0.80	2.00
UV	ARF	Dig	Ordnance	105mm - Partial	1	1	100%	0.04	4.00
UV	ARF	Dig	Ordnance	106mm	1	1	100%	0.09	3.00
UV	ARF	Dig	Ordnance	120mm	4	4	100%	0.38	3.00
UV	ARF	Dig	Ordnance	14in	1	1	100%	0.25	4.00
UV	ARF	Dig	Ordnance	155mm	16	17	94%	0.53	2.81
UV	ARF	Dig	Ordnance	175mm	1	1	100%	0.23	3.00
UV	ARF	Dig	Ordnance	2.75in Rocket	1	1	100%	0.72	3.00
UV	ARF	Dig	Ordnance	240mm	1	1	100%	0.49	2.00
UV	ARF	Dig	Ordnance	5in	2	2	100%	0.28	3.50
UV	ARF	Dig	Ordnance	6in	1	1	100%	0.24	4.00
UV	ARF	Dig	Ordnance	75mm	3	3	100%	0.55	3.33
UV	ARF	Dig	Ordnance	8in	3	3	100%	0.62	2.67
UV	ARF	Dig	Ordnance	90mm	8	10	80%	0.64	2.75
UV	ARF	Dig	Ordnance	90mm - Partial	2	2	100%	1.12	2.00
UV	ARF	Dig	Ordnance	Butterfly bomb	1	1	100%	0.54	2.00
UV	ARF	Seed	Ordnance	105mm	5	32	16%	0.70	4.40

UV	ARF	Seed	Ordnance	81mm	4	32	13%	0.80	3.25
UV	AF	Calib	Ordnance	105mm	2	2	100%	0.53	2.00
UV	AF	Calib	Ordnance	155mm	2	2	100%	0.83	1.50
UV	AF	Calib	Ordnance	2.75 in	1	2	50%	0.97	1.00
UV	AF	Calib	Ordnance	60mm	1	2	50%	0.67	2.00
UV	AF	Calib	Ordnance	81mm	2	2	100%	0.87	1.50
UV	AF	Seed	Ordnance	105mm	21	28	75%	0.76	1.57
UV	AF	Seed	Ordnance	60mm	2	3	67%	0.74	2.50
UV	AF	Seed	Ordnance	81mm	4	21	19%	0.48	1.50
VG	AF	Seed	Ordnance	105mm	24	28	86%	0.80	2.08
VG	AF	Seed	Ordnance	60mm	2	3	67%	0.59	1.50
VG	AF	Seed	Ordnance	81mm	10	21	48%	0.89	1.80

Table 4.7 Dig Results for 2m search radius, broken down by ordnance type

System	Area	Class	Classification	Type	Found	Emplaced	Rate	Avg Err	Avg Prior
DAS	ARF	Dig	C	Frag	10	60	17%	0.65	3.00
DAS	ARF	Dig	C	Scrap	8	18	44%	0.70	3.88
DAS	ARF	Dig	Ordnance	105mm	1	1	100%	0.95	2.00
DAS	ARF	Dig	Ordnance	106mm	1	1	100%	0.39	6.00
DAS	ARF	Dig	Ordnance	120mm	1	4	25%	0.14	6.00
DAS	ARF	Dig	Ordnance	14in	1	1	100%	0.20	6.00
DAS	ARF	Dig	Ordnance	155mm	4	17	24%	0.50	4.25
DAS	ARF	Dig	Ordnance	175mm	1	1	100%	0.64	2.00
DAS	ARF	Dig	Ordnance	8in	1	3	33%	1.54	3.00
DAS	ARF	Dig	Ordnance	90mm - Partial	2	2	100%	1.25	5.00
DAS	AF	Seed	Ordnance	105mm	19	28	68%	0.42	3.26
DAS	AF	Seed	Ordnance	60mm	2	3	67%	0.91	3.00
DAS	AF	Seed	Ordnance	81mm	8	21	38%	0.60	3.13
MV	ARF	Dig	C	Frag	59	60	98%	0.60	2.69
MV	ARF	Dig	C	Scrap	18	18	100%	0.56	2.78
MV	ARF	Dig	Ordnance	105mm	1	1	100%	0.80	1.00
MV	ARF	Dig	Ordnance	105mm - Partial	1	1	100%	0.04	4.00
MV	ARF	Dig	Ordnance	106mm	1	1	100%	0.09	4.00
MV	ARF	Dig	Ordnance	120mm	4	4	100%	0.38	3.25
MV	ARF	Dig	Ordnance	14in	1	1	100%	0.25	4.00
MV	ARF	Dig	Ordnance	155mm	17	17	100%	0.60	2.65
MV	ARF	Dig	Ordnance	175mm	1	1	100%	0.23	2.00

MV	ARF	Dig	Ordnance	2.75in Rocket	1	1	100%	0.72	3.00
MV	ARF	Dig	Ordnance	240mm	1	1	100%	0.49	3.00
MV	ARF	Dig	Ordnance	5in	2	2	100%	0.28	3.00
MV	ARF	Dig	Ordnance	6in	1	1	100%	0.24	2.00
MV	ARF	Dig	Ordnance	75mm	3	3	100%	0.55	3.00
MV	ARF	Dig	Ordnance	8in	3	3	100%	0.62	3.33
MV	ARF	Dig	Ordnance	90mm	9	10	90%	0.76	2.78
MV	ARF	Dig	Ordnance	90mm - Partial	2	2	100%	1.12	1.00
MV	ARF	Dig	Ordnance	Butterfly bomb	1	1	100%	0.54	2.00
MV	ARF	Seed	Ordnance	105mm	6	32	19%	0.92	3.67
MV	ARF	Seed	Ordnance	81mm	5	32	16%	1.01	4.20
MV	AF	Calib	Ordnance	105mm	2	2	100%	0.53	2.00
MV	AF	Calib	Ordnance	155mm	2	2	100%	0.83	2.00
MV	AF	Calib	Ordnance	2.75 in	2	2	100%	1.24	1.50
MV	AF	Calib	Ordnance	60mm	1	2	50%	0.67	2.00
MV	AF	Calib	Ordnance	81mm	2	2	100%	0.87	2.00
MV	AF	Seed	Ordnance	105mm	22	28	79%	0.81	3.09
MV	AF	Seed	Ordnance	60mm	2	3	67%	0.74	4.00
MV	AF	Seed	Ordnance	81mm	5	21	24%	0.78	2.80
UV	ARF	Dig	C	Frag	59	60	98%	0.60	3.31
UV	ARF	Dig	C	Scrap	18	18	100%	0.56	2.89
UV	ARF	Dig	Ordnance	105mm	1	1	100%	0.80	2.00
UV	ARF	Dig	Ordnance	105mm - Partial	1	1	100%	0.04	4.00
UV	ARF	Dig	Ordnance	106mm	1	1	100%	0.09	3.00
UV	ARF	Dig	Ordnance	120mm	4	4	100%	0.38	3.00
UV	ARF	Dig	Ordnance	14in	1	1	100%	0.25	4.00
UV	ARF	Dig	Ordnance	155mm	17	17	100%	0.60	2.76
UV	ARF	Dig	Ordnance	175mm	1	1	100%	0.23	3.00
UV	ARF	Dig	Ordnance	2.75in Rocket	1	1	100%	0.72	3.00
UV	ARF	Dig	Ordnance	240mm	1	1	100%	0.49	2.00
UV	ARF	Dig	Ordnance	5in	2	2	100%	0.28	3.50
UV	ARF	Dig	Ordnance	6in	1	1	100%	0.24	4.00
UV	ARF	Dig	Ordnance	75mm	3	3	100%	0.55	3.33
UV	ARF	Dig	Ordnance	8in	3	3	100%	0.62	2.67
UV	ARF	Dig	Ordnance	90mm	9	10	90%	0.76	2.67
UV	ARF	Dig	Ordnance	90mm - Partial	2	2	100%	1.12	2.00

UV	ARF	Dig	Ordnance	Butterfly bomb	1	1	100%	0.54	2.00
UV	ARF	Seed	Ordnance	105mm	6	32	19%	0.92	4.33
UV	ARF	Seed	Ordnance	81mm	5	32	16%	1.01	3.20
UV	AF	Calib	Ordnance	105mm	2	2	100%	0.53	2.00
UV	AF	Calib	Ordnance	155mm	2	2	100%	0.83	1.50
UV	AF	Calib	Ordnance	2.75 in	2	2	100%	1.24	3.00
UV	AF	Calib	Ordnance	60mm	1	2	50%	0.67	2.00
UV	AF	Calib	Ordnance	81mm	2	2	100%	0.87	1.50
UV	AF	Seed	Ordnance	105mm	22	28	79%	0.81	1.64
UV	AF	Seed	Ordnance	60mm	2	3	67%	0.74	2.50
UV	AF	Seed	Ordnance	81mm	5	21	24%	0.78	1.40
VG	AF	Seed	Ordnance	105mm	25	28	89%	0.83	2.04
VG	AF	Seed	Ordnance	60mm	2	3	67%	0.59	1.50
VG	AF	Seed	Ordnance	81mm	12	21	57%	1.01	1.92

Table 4.8 Summary of dig results at ARF, comparing all digs to those where flight altitude was less than 3m for the three selected search radii

System	**Type**	**2m all %Found**	**2m <3 %Found**	**1.5m all % Found**	**1.5m <3 %Found**	**1m all % Found**	**1m <3 %Found**
DAS	Frag	18%	17%	17%	15%	13%	11%
DAS	Scrap	27%	27%	27%	27%	19%	19%
DAS	Ordnance	13%	15%	12%	14%	11%	13%
MV	Frag	99%	99%	99%	99%	90%	90%
MV	Scrap	100%	100%	96%	96%	96%	96%
MV	Ordnance	61%	72%	57%	68%	49%	59%
UV	Frag	99%	99%	99%	99%	90%	90%
UV	Scrap	100%	100%	96%	96%	96%	96%
UV	Ordnance	61%	72%	57%	68%	49%	59%

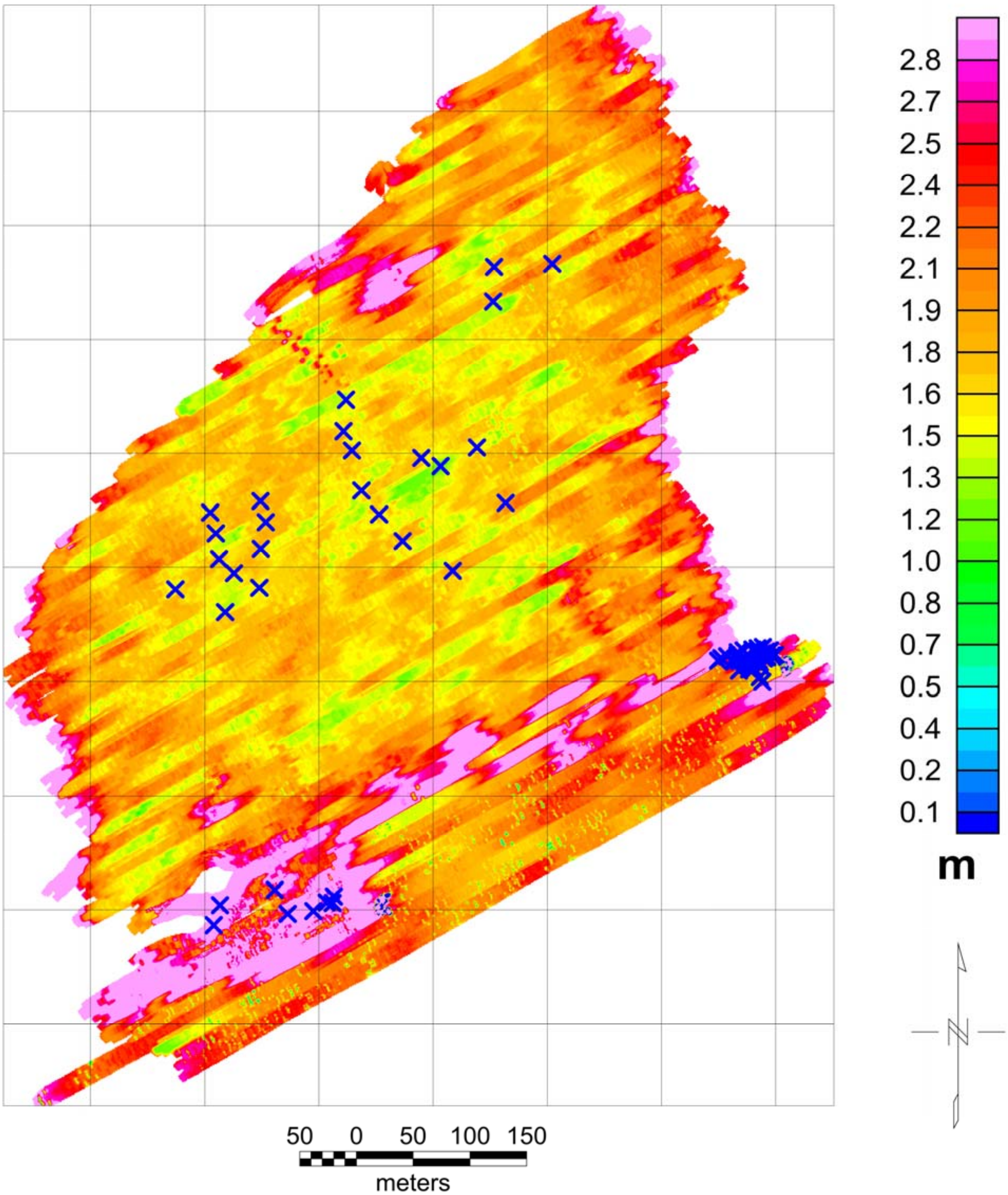


Figure 4.12. Locations of anomalies excavated at ARF superimposed on a map of the altitude at which airborne data were acquired.

4.4 Technical Conclusions

The performance of the ORAGS-Arrowhead total field magnetometer system at APG was lower than experienced at other sites where we have worked. We credit this in part to higher flight altitudes, particularly at the MGD and DP, and somewhat higher noise levels. Over all sites, the altitudes were more variable than we typically experience. Flight altitudes are left to pilot judgment as a safety issue, and we must assume that the pilot felt that it was inappropriate to fly as low at APG as at other sites. Locations of many of the seed items coincided with portions of the survey area where data acquisition was particularly high, leading to even poorer performance assessments. Mean anomaly position errors were less than one meter, even when a 2-meter search radius was used. At the larger areas surveyed (DP and MGD), the ORAGS-Arrowhead system was able to collect data at a rate of in excess of 100 acres per hour, a figure that includes turn around time at the ends of lines. This is representative of acquisition rates we have used in "production" surveys at other sites. Lower acquisition rates (70 and 78 acres/hr) were achieved at the two smaller sites (ARF and AF), which is consistent with our experience for such small targets. Peak-to-peak noise levels in the raw magnetic data were within 1 nT in 6 of 8 sensors. In the two inboard sensors of the rear booms, noise levels were about 2 nT. Once filters were applied to noise induced by the blades and rotor, noise levels were reduced to 0.1-0.2 nT in all sensors.

Although dig procedures that were used do not allow calculation of false positives and false negatives, we can address the effectiveness of the sorting routines that were used. For the univariate picking procedure and 2m search radius, 47.5% of the ordnance items detected were identified as category 1 or 2 (most-likely or probably UXO), 46.7% were identified as category 3 or 4 (possibly UXO or possibly scrap) and only 5.7 were identified as category 5 or 6 (most-likely or probably scrap). Similarly for ordnance fragments, using the same picking routine and search radius, 35.7% were identified as category 1 or 2, 57.8 were identified as category 3 or 4, and 11.4% were identified as category 5 or 6. For scrap, 48.6% were identified as category 1 or 2, 45.7 were identified as category 3 or 4, and 5.7% were identified as category 5 or 6. These results demonstrate that either the anomalies from scrap and UXO are too similar to distinguish between them, or that the library from which the statistical sorting parameters were chosen was inadequate, either in lacking an acceptable distribution of ordnance and non-ordnance items, or in the types of ordnance that were used to select the parameters. As these were preliminary sorting routines, this is not a surprising result. Improvements can be made in the statistical sorting procedures by incorporating the validation data acquired at APG.

5.0 Cost Assessment

5.1 Cost Reporting

Cost information associated with the demonstration of all airborne technology, as well as associated activities, were closely tracked and documented before, during, and after the demonstration to provide a basis for determination of the operational costs associated with this technology. It is important to note that the costs for airborne surveys are very much dependent on the character, size, and conditions at each site; ordnance objectives of the survey (e.g. flight altitude); type of survey conducted (e.g. high-density or transects); and technology employed for the survey (e.g. total field magnetic) so that a universal formula cannot be fully developed. For this demonstration, the following table contains the cost elements that were tracked and documented for this demonstration. These costs include both operational and capital costs associated with system design and construction; salary and travel costs for support staff; subcontract costs associated with helicopter services, support personnel, and leased equipment; costs associated with the processing, analysis, comparison, and interpretation of airborne results generated by this demonstration.

Table 5.1 Survey Cost Assessment

Cost Category	Sub Category	Details	Quantity	Cost[1] (in dollars)
Pre-Survey (Start-up)	Site Characterization	Site inspection (includes hotel and per diem)	1 day	$1,869
	Mobilization	Mission Plan preparation & logistics (a portion of the effort is covered under the corresponding vertical gradient project)	2 days	$3,538
		Calibration Site development (provided by Aberdeen Testing Center and ESTCP)	0 days	$0
		Equipment/personnel packing and transport	1-1/2 days	$5,773
		Helicopter/personnel transport	1 day (7 hours airtime)	$6,237
		Unpacking and system installation	0.5 day	$2,279
		System testing & calibration	0.5 day	$3,154
Pre-survey subtotal				$22,850
	Cesium-vapor magnetometers	$122,200 total cost	8 each	$12,220
	GPS	$15,500 total cost	1 each	$1,550
	Booms and mounting hardware	$36,500 total cost	1 set	$3,650

Capital Equipment[2]	Orientation system	$16,600 total cost	1 each	$1,660
	Fluxgate magnetometer	$5,300 total cost	1 each	$530
	Navigation system	$5,200 total cost	1 each	$520
	Laser Altimeter	$7,300 total cost	1 each	$730
	Data management console	$31,200 total cost	1 each	$3,120
	Magnetic base station	$15,100 total cost	1 each	$1,510
	GPS base station	$15,600 total cost	1 each	$1,560
	PCs for data processing & analysis	$3,450 total cost	2 each	$345
	Shipping Cases	$4,750 total cost	6 each	$475
	Trailer	$3,600 total cost	1 each	$360
Capital subtotal				$28,230

Operating Costs	Equipment Rental	Spare magnetometers	2 each	$840
		GPS equipment	1 each	$950
	Data acquisition	Helicopter time, including pilot and engineer labor	7 days (68 hours airtime)	$57,828
	Operator labor		7 days	$1,869
	Data processing	Geophysicist	7 days (84 hours labor)	$10,785
	Field support/ management	Engineer	7 days (84 hours labor)	$12,383
	Maintenance	Geosoft software maintenance[3]	1 each	$1,243
	Hotel and per diem	Survey team in Aberdeen	7 days	$3,514
	Fuel Truck	Remote re-fueling	-	$0
	Data analysis and interpretation	Geophysicist	20 days	$33,890
	Project management		14 days	$21,563
	Reporting and documentation		18 days	$27,724
Operating cost subtotal				$172,589
Post-Survey	Demobilization	Disassembly from helicopter	0.5 day	$2,279
		Equipment/personnel transport (includes travel, packing, and	1-1/2 days	$5,773

		loading for transport) Helicopter/personnel transport (includes travel)	1 days (7 hours airtime)	$6,237
Post-survey Subtotal				$14,289
Indirect Environmental Activity Costs	Environmental and Safety Training	8-hour HAZWOPR (includes the course cost)	-	$0
Miscellaneous	Department of Energy Federal Acquisition Cost (FAC)	3% of project total; Congressionally-mandated charge for administering the Work-for-Others (WFO) program		$7,139
Total Costs				$245,097

[1]Includes all overhead and organization burden, fees, and associated taxes
[2]Capital costs are apportioned at 10% of the original equipment cost for this project; all capital equipment was used for several projects during the course of the year in which this project occurred
[3]Geosoft software costs include the cost of 1 license and the UX-Detect module. The license cost is apportioned at 10% of the total cost for this project in a similar fashion to the capital equipment costs

6.0 Implementation Issues

6.1 Environmental Checklist

In order to operate, each system must have Federal Aviation Administration approval (Supplemental Type Certificate). The required testing and evaluation performed in Toronto before mobilization to Maryland has been completed. In addition, ground crews are required to complete the 40-hour HAZWOPR course and to maintain their annual 8-hour refreshers for operation at most UXO sites.

6.2 Other Regulatory Issues

There are no additional regulatory requirements for operation at either site in Maryland.

6.3 End-User Issues

The primary stakeholders for UXO issues at the APG site in Maryland are the residents of the community surrounding APG, the Directorate of Safety, Health, and Environment (APG), and State of Maryland regulatory authorities. Airborne UXO surveys including larger scale surveys, are being designed to accommodate the limitations and needs of other sites. Efforts to commercialize the existing technology have led to shared operation with one contractor for engineering evaluation/cost analysis (EE/CA) activities. As new systems are developed and proven, they will enter into the same cycle of application and commercialization.

7.0 References

Beard, L.P., D.A. Wolf, B. Spurgeon, T.J. Gamey, and W.E. Doll, 2003, Rapid screening of large area magnetic data for unexploded ordnance: Expanded abstract in Proceedings of 2003 SAGEEP Symposium, San Antonio.

Doll, W. E., P. Hamlett, J. Smyre, D. Bell, J. E. Nyquist, T. J. Gamey, and J. S. Holladay, 1999, A field evaluation of airborne techniques for detection of unexploded ordnance. Proceedings of the Symposium on the Application of Geophysics to Engineering and Environmental Problems, 1999, p. 773-782.

Doll, W. E., T.J. Gamey, and J.S. Holladay, 2001, Current Research into Airborne UXO detection, Proceedings of the Symposium on the Application of Geophysics to Engineering and Environmental Problems, Denver, CO, available on CD-ROM, 10 pgs.

Gamey, T J., W. E. Doll, D. T. Bell, and J. S. Holladay, 2001, Current research into airborne UXO detection – Electromagnetics, UXO Forum, New Orleans, April 2001.

Gamey, T. J., W. E. Doll, A. Duffy, and D. S. Millhouse, 2000, Evaluation of improved airborne techniques for detection of UXO, Proceedings of the Symposium on the Application of Geophysics to Engineering and Environmental Problems, p. 57-66.

Nelson, H.H. and J.R. McDonald, 1999, Target shape classification using the MTADS: UXO/Countermine Forum 1999 Proceedings, Alexandria, Virginia, on CD-ROM.

ORNL, 2004, Draft Final Report on 2002 Airborne Geophysical Survey at Badlands Bombing Range, South Dakota: ESTCP Project 20037, 59 pp.

Swan, A.R.H. and M. Sandilands, 1995, Introduction to Geological Data Analysis, Blackwell Science, 446 pp.

Van, G.P., G. Calvert, L.P. Beard, T.J. Gamey, and A. M. Emond, 2004, Validation of Helicopter-Based Magnetic Survey at the Former Badlands Bombing Range: Expanded abstract in Proceedings of the Sixth Monterey Demining Symposium (MINWARA): Monterey, California, May 09-13, 2004.

Zapata Engineering, 2004, Site specific final report for ordnance and explosive removal action at Former Camp Wellfleet, Wellfleet, Massachusetts: Prepared for U.S. Army Engineering and Support Center, Huntsville, Alabama.

8.0 Points of Contact

Points of contact are given below in Table 8.1.

Table 8.1: Points of Contact

NAME	**ORGANIZATION**	**PHONE**	**Role in Project**
Gary Jacobs	ORNL	865-576-0567	Division Director
David T. Bell	ORNL	865-574-2855, 865-250-0578 (cellular)	Project Manager
Dr. Bill Doll	ORNL	865-576-9930	Technical Manager
Jeff Gamey	ORNL	865-574-6316 865-599-0820 (cellular)	Operations Manager
Dr. Les Beard	ORNL	865-576-4646	Geophysicist
D. Scott Millhouse	USAESCH	256-895-1607	Project Lead
Mr. Gary Rowe	APG Staff	410-278-5498	Site Interface
Dan Munro	National Helicopters	416-990-2727	Helicopter Contractor President

Appendix A: Analytical Methods Supporting the Experimental Design

A.1 Statistically based UXO discrimination

We began investigating statistically-based discrimination methods after an analysis of dig results based on data collected at the former Badlands Bombing Range (BBR) in South Dakota showed statistical differences between ordnance and non-ordnance. In no instance was the statistical difference so strong that a single parameter could predict whether the source of an anomaly was UXO or not, but the possibility for discrimination increased as more parameters were considered. We used a routine developed to our specifications by Geosoft to rapidly identify and characterize anomalies above a given threshold from an analytical signal map. From these peaks we identified the associated magnetic field anomaly and sensor altitude, and computed a number of parameters that could be used directly or otherwise combined as statistically relevant predictors. From this point we used two different approaches for discrimination— univariate and multivariate methods.

A.1.1 Univariate method

The univariate method relies on correlations from dig results based on airborne magnetic data collected at two different sites: an East Coast site and BBR. Both sites were geologically 'clean' in that neither contained basaltic rock or magnetic soils that could complicate any interpretations. We chose six parameters showing correlation with known UXO, and at each anomaly location evaluated whether the parameters fell within the range of the majority of known measured UXO. Each of the six parameters was scored zero if the parameter fell outside a specified range, and one if it fell within the range. For example, almost all ordnance in our known sample pool yielded peak-to-peak magnetic anomalies between 1.0 and 80 nT. Any anomaly falling outside this range was scored zero, as non-UXO. The six characteristics were scored and summed, so that items could have a value ranging from 6 (all characteristics in the range of UXO) to zero (all characteristics outside the range for UXO). The six parameters used in the univariate analysis were analytic signal amplitude, magnetic anomaly peak-to-peak magnitude, the distance between the magnetic anomaly peak and low, the ratio of the positive magnetic anomaly lobe to the peak-to-peak magnitude, the estimated source depth, and the angle between magnetic north and the line connecting the positive and negative lobes of the magnetic anomaly (denoted theta).

A.1.2 Multivariate method

Multivariate analysis should provide more information than the univariate approach described above as long as some or all of the variables are correlated, and if the number of known samples is large enough to obtain reliable statistics. The parameters must also be appropriately normalized to remove the effects of different magnitudes for the given parameters. We derived a vector of standard mean parameters $\boldsymbol{\mu}_0$ from a set of measurements over known ordnance items, and compute the symmetric covariance matrix $\mathbf{S}$ from the covariances computed for the different

variable combinations. The statistical similarity between the known ordnance and the parameter vector **x** associated with an unknown is given by the Mahalanobis distance (Swan and Sandilands, 1995)

$$D = \{(\mathbf{x} - \mu_0)^T \mathbf{S}^{-1} (\mathbf{x} - \mu_0)\}^{1/2}. \quad (1)$$

The smaller the Mahalanobis distance the more closely the unknown resembles ordnance from the known pool of items. The vectors **x** and μ_0 each have five entries: analytic signal peak, the magnitude of the negative lobe of the magnetic anomaly, the ratio of the positive magnetic anomaly lobe to the peak-to-peak magnitude, the ratio of the distance between the magnetic anomaly positive peak and the analytic signal peak to the instrument height added to the estimated source depth, and theta, as described in the univariate section. The differences in the variables used in the two methods of analysis occurred because the univariate analysis was done prior to a more complete statistical review of the data, which led to the multivariate approach.

A.2 Model-based inversion of magnetic data as an aid to discrimination

Magnetic fields in the vicinity of UXO can often be reliably estimated using a model based on a magnetic dipole. The DAS software (Nelson and McDonald, 1999) is based on this model. DAS is not perform discrimination, but rather is an aid to the interpreter, who subjectively performs the discrimination task. DAS requires as input a set of coordinates (x,y,z) and a magnetic total field measurement at each coordinate. The software constructs a grid of the total field data from which the interpreter can select individual anomalies as likely UXO targets. The user selects a boundary around the anomaly that includes some area outside the main anomaly, and the DAS code searches for a dipole model that best fits the selected data. Output are estimates of the moment of the magnetic dipole, its length, orientation, burial depth, and goodness of fit. From the returned parameters, an experienced interpreter can make a reasonably well-informed judgment as to whether or not the source of the anomaly is intact ordnance, scrap, or non-UXO related.

Appendix B: Quality Assurance Project Plan (QAPP)

At the time of this survey, we were not required to have a QAPP in place, nor had ESTCP published the current guidelines for QAPP documentation (ESTCP Final Report Guidance for UXO Projects, Revision 2, April 2002). We nevertheless developed our own QA/QC procedures that were followed through this and other projects. These fall into three main categories: operational QA/QC, system QA/QC, and data QA/QC.

Under the category of operational QA/QC:

- Site visit preliminary to survey to assess appropriateness of site for helicopter geophysical surveying;
- De-gaussing of helicopter rotor to decrease magnetic noise produced by this component;
- Review of GPS almanac to assess best times of the day for surveying;
- Emplacement of a calibration grid for daily system checks;
- A morning meeting to coordinate each day's activities;
- An evening meeting to review activities and safety issues.

Under the category of system QA/QC:

- Installation of booms under the supervision of the pilot and engineer, and subsequent double-checking of all mounts and bolts;
- Daily helicopter inspection and maintenance by pilot and engineer;
- Ground tests of system after installation (checks to determine if all magnetometers are operating and have been connected in the correct order, and an impulse test to determine the lag between magnetometers and fluxgate);
- An initial check flight after installation.

Under the category of data QA/QC:

- An extensive test flight to evaluate the effects of pitch, roll, and yaw on the magnetometers, from which we can calculate compensation coefficients, and to examine the high altitude noise levels of the magnetometers.
- Daily inspection of diurnal magnetic activity at a base station magnetometer;
- Visual inspection of all data;
- Daily plots of flight path and laser altitude;
- Adherence to the data processing flow, described in section 3.6.6;
- Daily production of digital magnetic maps;
- Archiving of all materials: flight logs, digital materials, and report.

Appendix C: Health and Safety Plan

This document represents the health and safety plan applied to field operations in Maryland.

C.1 Aircraft Base of Operations

Aberdeen Proving Ground
Aberdeen, MD
Phone: 410-671-3536/3385

The base of operations for all aircraft activities will be Aberdeen Proving Ground. The aircraft will be stored and some refueling activities will occur at this location (although APG only has JP8 fuel available on-site). Other refueling activities will occur remotely through use of a fuel truck provided by National Helicopters, Inc.

C.2Hotel, ORNL and National Helicopters Staff

Country Inn and Suites
Exit 80 off I-95
Belcamp, Maryland 21017
Phone: 410-297-9444

C.3 Communications

Air-to-ground and ground-to-ground communications will occur using two-way VHF radios provided by ORNL and National Helicopters. Radios will broadcast at 118 - 135 MHz. All other communications will be via cellular telephones.

Note: Authorization to enter the airspace over the test range areas is controlled by the Range Control Officer in B-Tower. Please contact the Range Control Officer at 410-278-2250 (local 3-2250) prior to ingress and egress of the survey areas.

C.4 Schedule Constraints and Crew Rest

C.4.1 Schedule Constraints

During aviation missions, activities can occur that are uncontrollable by the survey team and cause a delay of data acquisition. These activities may result in missed data acquisition windows or the loss of entire days of data acquisition.

C.4.2 Crew Rest

Crew rest will follow the guidelines prescribed by FAA regulations. Restrictions are placed on both the pilot's in-air flight-time and duty-time.

C.5 Aircraft

Bell 206L Long Ranger III Helicopter	National Helicopters, Inc.
Color scheme: White with midnight blue and light blue accents	11339 Albion Vaughn Road Kleinburg, Ontario, Canada
Serial Number: 45478	Phone: 905-893-2727
Tail Number: C-FLYC	

C.6 Statement of Risks

Airborne geophysical surveys are designed to be conducted with minimal risk to personnel. <u>Safe operation of the aircraft is the ***direct responsibility*** of the pilot, who will determine the minimum safe flight altitude and local weather conditions for safe flying on an ongoing basis</u>. The mission will be flown under all applicable Federal Regulations.

Most ground activities will be limited to routine working conditions; however certain field activities will expose personnel to summer heat and prairie wildlife. Precautions against the heat include drinking plenty of water, using sunscreen, and taking breaks as needed. Precautions against the wildlife include wearing hiking (or similar) boots and minimization of exposure to that environment. In addition, the two-man rule will be in effect for all on-site field activities.

For additional risk-related information, consult the Operational Emergency Response Plan contained in Appendix B of this document.

Note: This system utilizes a laser altimeter. The laser is eye safe and rated as a Class 1 laser in accordance with Food and Drug Administration Code of Federal Regulations (CFR) Chapter 1, part 1040.10 (Laser Products). However, to ensure continued eye safety associated with system operation, all personnel in the area where the system is in operation will refrain from the use of any optical instruments directed at the airborne system while in flight (e.g. binoculars).

C.7 Emergency Notification

Emergency action plans are included in the Appendix of this document. In the event of an emergency, staff will first request assistance, then provide appropriate first aid measures until

emergency assistance arrives.

Hospitals – Harford Memorial Hospital
443-843-5000

501 South Union Avenue

Havre de Grace, Maryland 21078

Upper Chesapeake Medical Center 443-643-1000

500 Upper Chesapeake Drive

Bel Air, Maryland 21014

Police, Fire, Ambulance (on-site and off-site) 911

APG-Aberdeen Area Fire Department (on-site) 410-306-0572

APG-Aberdeen Area Ambulance (on-site) 410-306-2222

APG-Edgewood Area Fire Department (on-site) 410-436-4451

APG-Edgewood Area Ambulance (on-site) 410-436-2222

Aberdeen Police Department 410-272-2121

Aberdeen Fire Deparment 410-272-2211

Maryland State Police 410-486-3101

As soon as emergency assistance has been obtained, the following people will be notified in sequence based on availability:

Dr. Bill Doll, ORNL Project Manager	Cellular:	865-599-0820
	Office:	865-576-9930
Mr. Jeff Gamey, ORNL Operations Manager	Cellular:	865-599-0820
	Office:	865-574-6316
Dr. Les Beard, ORNL Technical Manager	Cellular:	865-599-0820
	Office:	865-574-4646
Mr. Gary Rowe, USAEC Senior Test Director	Office:	410-278-5498
Mr. Dan Munro, National Helicopter, President	Office:	905-893-2727
Dr. Steve Hildebrand, ORNL Environmental Sciences Division Director	Office:	865-574-7374
	Home:	865-966-6333

Each organizational member of the project team is responsible for flow-down of communications within the respective organization in the event of an incident or emergency (e.g. notification of next-of-kin by ORNL Environmental Sciences Division Director if ORNL staff is involved in an emergency situation, etc.). Any member of the project team, in the event of an emergency situation, shall **not** contact persons other than those designated in the above listing.

C.8 On-Site Ground Emergencies

In the event of an emergency that occurs on-site:

1) Telephone local emergency response organizations via 911, if needed.
2) Conduct appropriate first aid.
3) Notify managers, as listed above in sequence. **The ORNL Project Manager has jurisdiction for all on-site emergency activities.** If the ORNL Project Manager is not available, the ORNL Technical Manager has jurisdiction.
4) The pilot has jurisdiction for emergency response when the aircraft is airborne, has crashed (if able), or has an emergency situation on the ground.
5) In the event of a catastrophic accident, the ORNL Environmental Sciences Division Director shall be notified immediately, and included in all response team activities, including communication, emergency response, and reporting.

C.9 Off-Site Ground Emergencies

In the event of an emergency that occurs off-site:

1) Assess the urgency of the emergency.
2) Telephone local emergency response organizations via 911, if needed.
3) Conduct appropriate first aid while awaiting professional assistance.
4) Notify managers, as listed above in sequence. **<u>The ORNL Project Manager has jurisdiction for all off-site emergency activities.</u>** If the ORNL Project Manager is not available, the ORNL Technical Manager has jurisdiction.
5) The pilot has jurisdiction for emergency response when the aircraft is airborne, has crashed (if able), or has an emergency situation on the ground.
6) In the event of a catastrophic accident, the ORNL Environmental Sciences Division Director shall be notified immediately, and included in all response team activities, including communication, emergency response, and reporting.

C.10 In-Air Emergencies

In-air emergencies will be handled via standard aircraft emergency protocol, including radio contact with the Rapid City Regional Airport. **<u>The pilot has jurisdiction for all emergency response activities and requirements when the aircraft is airborne.</u>** Follow-up telephone/radio notification to the emergency response personnel will be made as soon as possible.

Appendix D: Data Storage and Archiving Procedures

General

Digital data are on the CD accompanying this report. Included are: (1) readme files, (2) a copy of the final report in *.DOC format, (3) digital copies of the total field and analytic signal maps from each area flown (ARF, MGD, DP and AF) in JPG format, (4) dig lists in ASCII format, (5) geophysical data files in ASCII format, (6) ORNL analysis files, and (8) excavation and remediation results.

Geophysical Data

The data included with this report is ASCII text and conforms to the format described in the "Area_Data_Readme.txt" file on the CD-ROM provided. Files are named according to area surveyed: ARF_MAG.XYZ, MGD_MAG.XYZ, DP_MAG.XYZ and AF_MAG.XYZ. Coordinates are UTM Zone 18 N, NAD83 (Continental US).

ASCII text file format is comma delimited in the following order:

Column 1: Easting coord (m)
Column 2: Northing coord (m)
Column 3: Line ID
Column 4: laser altimeter (m)
Column 5: raw magnetic signal (nT)
Column 6: residual total magnetic field (nT)

Dig Lists

The dig list information is saved in an ASCII text format file. Numerous dig lists were required of us during the project. Accompanying this document are ASCII files comprising locations for excavation at sites ARF, MGD, DP, AF, and the calibration site (CAL) from APG, Maryland. The data from which the choices were made comes from a 2002 ORNL helicopter geophysical survey. The locations chosen are derived from dipole fitting using the DAS software, from multivariate statistical analysis, from univariate statistical analysis, and from visual inspection of the raw data. Coordinates are given in UTM Zone 18 N (meters) using a NAD83 (Continental US) datum, as well as in geographical latitude/longitude. All picks are prioritized 1-6 according to likelihood of being UXO (1= highest likelihood, 6=lowest).

ARF_das.xyz— Targets generated using DAS
ARF_uv.xyz --- Targets generated using univariate analysis
ARF_mv.xyz --- Targets generated using multivariate analysis

AF_das.xyz— Targets generated using DAS
AF_uv.xyz--- Targets generated using univariate analysis
AF_mv.xyz--- Targets generated using multivariate analysis

MGD_das.xyz— Targets generated using DAS
MGD_uv.xyz--- Targets generated using univariate analysis
MGD_mv.xyz--- Targets generated using multivariate analysis

DP_das.xyz— Targets generated using DAS
DP_uv.xyz--- Targets generated using univariate analysis
DP_mv.xyz--- Targets generated using multivariate analysis

cal_uv.xyz--- Targets generated using univariate analysis
cal_mv.xyz--- Targets generated using multivariate analysis

Images

Geophysical anomaly maps (total field residual and/or analytic signal) for each area (ARF, MGD, DP, and AF) are provided as image files in JPG formats. The JPG images have been saved at 200dpi at the scale labeled on each map. These files have the form Area_TF.JPG and Area_AS.JPG.

Appendix E. Validation Results Provided by ESTCP Project Office

DigID	OrigID	Class	Type	Description	Alt	AF_VG	AZIMUTH	DEPTH	OrigID2	INCLINATI	Weight__g	Dimension	Area
Dig-9	Dig-9	Dig	Ordnance	120-mm projectile fuzed, fired	1.66			0.631	S	20 NU	Not weigh	Not Recor	ARF
PAF-81-9	PAF-81-9	Seed	Ordnance	81mm	1.26	1.52	0	0.53	147	75			AF
PAF-81-6	PAF-81-6	Seed	Ordnance	81mm	1.02	2.55	0	0.11	170	0			AF
PAF-81-3	PAF-81-3	Seed	Ordnance	81mm	1.07	1.48	0	0.11	24	45			AF
PAF-81-26	PAF-81-26	Seed	Ordnance	81mm	1.25	0.27	0	0.95	179	45			AF
PAF-81-22	PAF-81-22	Seed	Ordnance	81mm	1.82	2.36	0	0.95	178	75			AF
PAF-81-18	PAF-81-18	Seed	Ordnance	81mm	1.20	0.21	0	0.53	122	45			AF
PAF-81-16	PAF-81-16	Seed	Ordnance	81mm	1.34	3.48	0	0.53	156	45			AF
PAF-81-10	PAF-81-10	Seed	Ordnance	81mm	1.15	2.89	0	0.11	149	45			AF
PAF-81-1	PAF-81-1	Seed	Ordnance	81mm	1.37	-0.50	0	0.53	154	0			AF
PAF-60-3	PAF-60-3	Seed	Ordnance	60mm	0.94	2.62	0	0	23	0			AF
PAF-105-9	PAF-105-9	Seed	Ordnance	105mm	1.20	-4.55	0	0.09	209	45			AF
PAF-105-8	PAF-105-8	Seed	Ordnance	105mm	1.30	10.12	0	0.46	140	75			AF
PAF-105-5	PAF-105-5	Seed	Ordnance	105mm	1.34	-4.84	0	0.09	151	0			AF
PAF-105-3	PAF-105-31	Seed	Ordnance	105mm	1.60	5.57	0	0.46	136	0			AF
PAF-105-2	PAF-105-26	Seed	Ordnance	105mm	1.39	12.16	0	0.82	213	75			AF
PAF-105-1	PAF-105-19	Seed	Ordnance	105mm	1.34	23.13	0	0.46	181				AF
PAF-105-1	PAF-105-17	Seed	Ordnance	105mm	1.38	8.03	0	0.46	166				AF
PAF-105-1	PAF-105-13	Seed	Ordnance	105mm	1.37	9.84	0	0.09	150				AF
PAF-105-1	PAF-105-11	Seed	Ordnance	105mm	1.22	-6.39	0	0.46	169				AF
PAF-105-1	PAF-105-1	Seed	Ordnance	105mm	1.06	0.14	0	0.82	170				AF
AP-105-1	AP-105-1	Seed	Ordnance	105mm	1.89		0	0.46	115				ARF
AP-105-10	AP-105-10	Seed	Ordnance	105mm	1.82		0	0.46	122				ARF
AP-105-7	AP-105-7	Seed	Ordnance	105mm	1.19		0	0.82	121				ARF
AP-81-11	AP-81-11	Seed	Ordnance	81mm	1.72		0	0.53	15				ARF
AP-81-14	AP-81-14	Seed	Ordnance	81mm	1.70		0	0.53	13				ARF
AP-81-4	AP-81-4	Seed	Ordnance	81mm	1.72		0	0.53	3				ARF
AP-81-8	AP-81-8	Seed	Ordnance	81mm	2.06		0	0.53	2				ARF

AP-81-9	AP-81-9	Seed	Ordnance	81mm	1.57	0		0.53	8		ARF
APP-105-1	APP-105-1	Seed	Ordnance	105mm	3.01	0		0	Lost		ARF
APP-81-2	APP-81-2	Seed	Ordnance	81mm	3.20	0		0	22		ARF
APP-81-3	APP-81-3	Seed	Ordnance	81mm	4.39	0		0	23		ARF
APS-105-1	APS-105-10	Seed	Ordnance	105mm	3.78	0		0	160		ARF
APS-105-1	APS-105-14	Seed	Ordnance	105mm	3.50	0		0	229		ARF
APS-105-1	APS-105-17	Seed	Ordnance	105mm	4.61	0		0	228		ARF
APS-105-2	APS-105-2	Seed	Ordnance	105mm	4.68	0		0	190		ARF
APS-105-4	APS-105-4	Seed	Ordnance	105mm	3.47	0		0	231		ARF
APS-105-6	APS-105-6	Seed	Ordnance	105mm	3.01	0		0	215		ARF
APS-81-11	APS-81-11	Seed	Ordnance	81mm	3.52	0		0	19		ARF
APS-81-13	APS-81-13	Seed	Ordnance	81mm	4.14	0		0	138		ARF
APS-81-2	APS-81-2	Seed	Ordnance	81mm	2.18	0		0	140		ARF
APS-81-4	APS-81-4	Seed	Ordnance	81mm	2.27	0		0	144		ARF
APS-81-7	APS-81-7	Seed	Ordnance	81mm	3.60	0		0	18		ARF
PAF-81-7	PAF-81-7	Seed	Ordnance	81mm	1.18	0.59	45	0.95	151	45	AF
PAF-81-5	PAF-81-5	Seed	Ordnance	81mm	1.28	0.57	45	0.53	153	75	AF
PAF-81-20	PAF-81-20	Seed	Ordnance	81mm	1.49	3.39	45	0.11	16	75	AF
PAF-81-17	PAF-81-17	Seed	Ordnance	81mm	1.24	0.44	45	0.53	182	75	AF
PAF-81-14	PAF-81-14	Seed	Ordnance	81mm	1.34	2.18	45	0.53	155	75	AF
PAF-81-13	PAF-81-13	Seed	Ordnance	81mm	0.94	3.04	45	0.53	171	0	AF
PAF-81-11	PAF-81-11	Seed	Ordnance	81mm	1.23	2.06	45	0.53	146	75	AF
PAF-105-6	PAF-105-6	Seed	Ordnance	105mm	1.17	3.40	45	0.82	194	45	AF
PAF-105-3	PAF-105-36	Seed	Ordnance	105mm	1.26	7.54	45	0.46	168	0	AF
PAF-105-3	PAF-105-3	Seed	Ordnance	105mm	1.29	9.45	45	0.82	132	45	AF
PAF-105-2	PAF-105-24	Seed	Ordnance	105mm	1.15	21.07	45	0.09	135	75	AF
PAF-105-2	PAF-105-22	Seed	Ordnance	105mm	1.23	5.36	45	0.46	167	45	AF
PAF-105-2	PAF-105-2	Seed	Ordnance	105mm	1.30	3.19	45	0.46	139	75	AF
PAF-105-1	PAF-105-18	Seed	Ordnance	105mm	1.46	26.46	45	0.46	211		AF
PAF-105-1	PAF-105-15	Seed	Ordnance	105mm	1.34	22.50	45	0.46	164		AF
PAF-105-1	PAF-105-10	Seed	Ordnance	105mm	1.16	19.78	45	0.46	149		AF

AP-105-2	AP-105-2	Seed	Ordnance	105mm	1.84		45	0.46	117		ARF
AP-105-4	AP-105-4	Seed	Ordnance	105mm	1.44		45	0.09	120		ARF
AP-105-5	AP-105-5	Seed	Ordnance	105mm	1.66		45	0.09	123		ARF
AP-105-8	AP-105-8	Seed	Ordnance	105mm	1.46		45	0.09	125		ARF
AP-81-1	AP-81-1	Seed	Ordnance	81mm	1.50		45	0.11	4		ARF
AP-81-10	AP-81-10	Seed	Ordnance	81mm	1.71		45	0.11	7		ARF
AP-81-2	AP-81-2	Seed	Ordnance	81mm	1.72		45	0.11	5		ARF
AP-81-5	AP-81-5	Seed	Ordnance	81mm	1.68		45	0.11	6		ARF
APP-105-2	APP-105-2	Seed	Ordnance	105mm	3.12		45	0	Lost		ARF
APP-105-3	APP-105-3	Seed	Ordnance	105mm	3.50		45	0	Lost		ARF
APP-81-1	APP-81-1	Seed	Ordnance	81mm	3.43		45	0	21		ARF
APS-105-1	APS-105-12	Seed	Ordnance	105mm	3.58		45	0	217		ARF
APS-105-1	APS-105-15	Seed	Ordnance	105mm	3.07		45	0	232		ARF
APS-105-1	APS-105-18	Seed	Ordnance	105mm	5.16		45	0	235		ARF
APS-105-3	APS-105-3	Seed	Ordnance	105mm	4.14		45	0	156		ARF
APS-105-7	APS-105-7	Seed	Ordnance	105mm	2.82		45	0	191		ARF
APS-105-9	APS-105-9	Seed	Ordnance	105mm	3.76		45	0	218		ARF
APS-81-12	APS-81-12	Seed	Ordnance	81mm	3.74		45	0	17		ARF
APS-81-3	APS-81-3	Seed	Ordnance	81mm	2.24		45	0	27		ARF
APS-81-5	APS-81-5	Seed	Ordnance	81mm	1.66		45	0	136		ARF
APS-81-8	APS-81-8	Seed	Ordnance	81mm	3.14		45	0	142		ARF
APS-81-9	APS-81-9	Seed	Ordnance	81mm	2.89		45	0	137		ARF
PAF-81-8	PAF-81-8	Seed	Ordnance	81mm	1.03	5.00	90	0.11	145	75	AF
PAF-81-4	PAF-81-4	Seed	Ordnance	81mm	1.11	0.05	90	0.53	121	0	AF
PAF-81-21	PAF-81-21	Seed	Ordnance	81mm	1.00	0.66	90	0.53	175	45	AF
PAF-81-2	PAF-81-2	Seed	Ordnance	81mm	1.23	0.14	90	0.53	148	45	AF
PAF-81-12	PAF-81-12	Seed	Ordnance	81mm	1.21	2.06	90	0.53	150	75	AF
PAF-60-4	PAF-60-4	Seed	Ordnance	60mm	1.66	14.99	90	0	22	75	AF
PAF-60-2	PAF-60-2	Seed	Ordnance	60mm	1.79	1.54	90	0	31	45	AF
PAF-105-7	PAF-105-7	Seed	Ordnance	105mm	1.25	18.03	90	0.09	208	75	AF
PAF-105-4	PAF-105-4	Seed	Ordnance	105mm	1.27	17.94	90	0.46	182	75	AF

PAF-105-2	PAF-105-29	Seed	Ordnance	105mm	1.56	10.11	90	0.09	144	45	AF
PAF-105-2	PAF-105-25	Seed	Ordnance	105mm	1.41	20.35	90	0.09	180	45	AF
PAF-105-2	PAF-105-21	Seed	Ordnance	105mm	1.18	20.30	90	0.09	165	45	AF
PAF-105-1	PAF-105-16	Seed	Ordnance	105mm	1.37	2.55	90	0.09	142		AF
PAF-105-1	PAF-105-14	Seed	Ordnance	105mm	1.29	4.67	90	0.46	173		AF
PAF-105-1	PAF-105-12	Seed	Ordnance	105mm	1.34	6.46	90	0.46	152		AF
AP-105-3	AP-105-3	Seed	Ordnance	105mm	1.74		90	0.46	116		ARF
AP-105-6	AP-105-6	Seed	Ordnance	105mm	1.71		90	0.82	127		ARF
AP-105-9	AP-105-9	Seed	Ordnance	105mm	1.56		90	0.46	118		ARF
AP-81-12	AP-81-12	Seed	Ordnance	81mm	1.36		90	0.53	9		ARF
AP-81-13	AP-81-13	Seed	Ordnance	81mm	1.66		90	0.95	10		ARF
AP-81-3	AP-81-3	Seed	Ordnance	81mm	1.67		90	0.53	11		ARF
AP-81-6	AP-81-6	Seed	Ordnance	81mm	1.50		90	0.53	14		ARF
AP-81-7	AP-81-7	Seed	Ordnance	81mm	1.56		90	0.95	12		ARF
APP-105-4	APP-105-4	Seed	Ordnance	105mm	5.12		90	0	Lost		ARF
APP-81-4	APP-81-4	Seed	Ordnance	81mm	2.05		90	0	134		ARF
APS-105-1	APS-105-1	Seed	Ordnance	105mm	3.95		90	0	234		ARF
APS-105-1	APS-105-11	Seed	Ordnance	105mm	3.84		90	0	202		ARF
APS-105-1	APS-105-13	Seed	Ordnance	105mm	2.70		90	0	157		ARF
APS-105-1	APS-105-16	Seed	Ordnance	105mm	3.53		90	0	227		ARF
APS-105-5	APS-105-5	Seed	Ordnance	105mm	3.28		90	0	192		ARF
APS-105-8	APS-105-8	Seed	Ordnance	105mm	2.64		90	0	216		ARF
APS-81-1	APS-81-1	Seed	Ordnance	81mm	2.10		90	0	141		ARF
APS-81-10	APS-81-10	Seed	Ordnance	81mm	2.55		90	0	135		ARF
APS-81-14	APS-81-14	Seed	Ordnance	81mm	3.80		90	0	143		ARF
APS-81-6	APS-81-6	Seed	Ordnance	81mm	1.68		90	0	26		ARF
Cal-1	Cal-1	Cal	rdnance	60-mm	1.24		EW				cal
Cal-3	Cal-3	Cal	rdnance	81-mm	1.02		EW				cal
Cal-5	Cal-5	Cal	rdnance	2.75 in rocket	1.30		EW				cal
Cal-7	Cal-7	Cal	rdnance	105-mm	1.26		EW				cal
Cal-9	Cal-9	Cal	rdnance	155-mm	1.35		EW				cal

Cal-2	Cal-2	Cal	rdnance	60-mm	1.23		NS						cal
Cal-4	Cal-4	Cal	rdnance	81-mm	0.97		NS						cal
Cal-6	Cal-6	Cal	rdnance	2.75 in rocket	1.06		NS						cal
Cal-8	Cal-8	Cal	rdnance	105-mm	1.07		NS						cal
Cal-10	Cal-10	Cal	rdnance	155-mm	1.16		NS						cal
PAF-105-1	PAF-105-1A	Seed	Ordnance	105mm	1.27	0.26							AF
Dig-1	Dig-1	Dig	Frag	1/2 casing 280-mm	1.99			-0.932	Not Recor	90 NU		680 x 280	ARF
Dig-2	Dig-2	Dig	Scrap	1/2 Curled wire	1.17	2.59		0.1284	NA	NA	490	3700 x 12	AF
Dig-3	Dig-3	Dig	Ordnance	1/2 of 105-mm casing	1.47			-0.012	Not Recor	Not Recor	5690	340 x 110	ARF
Dig-4	Dig-4	Dig	Ordnance	1/2 of 90-mm casing	1.92			-0.044	Not Recor	Not Recor	3800	310 x 130	ARF
Dig-5	Dig-5	Dig	Ordnance	100-mm rocket, fired, unfuzed	1.94			0.237	SE	0	Not weigh	1500 x 10	ARF
Dig-6	Dig-6	Dig	Ordnance	105-mm fragment	1.79			0.14	E	60 NU	4980	370 x 120	ARF
Dig-7	Dig-7	Dig	Ordnance	105mm projectile, fired, fuzed	1.80			0.118	Lost	Lost	Not weigh	600 x 105	ARF
Dig-8	Dig-8	Dig	Ordnance	106-mm RAP round	1.73			0.594	SW	5 ND	Not weigh	400 x 106	ARF
Dig-10	Dig-10	Dig	Ordnance	120-mm projectile fuzed, fired	1.36			0.062	N	80 NU	Not weigh	590 x 120	ARF
Dig-11	Dig-11	Dig	Ordnance	120-mm projectile fuzed, fired	1.73			0.539	W	10 NU	Not weigh	250 x 120	ARF
Dig-12	Dig-12	Dig	Ordnance	120-mm projectile fuzed, fired	1.58			0.199	WSW	20 NU	Not weigh	527 x 120	ARF
Dig-13	Dig-13	Dig	Ordnance	14-in fuzed projectile	1.45			0.661	NW	0	Not weigh	1600 x 356	ARF
Dig-14	Dig-14	Dig	Ordnance	155-mm base	1.44			Lost	NA	NA	11300	240 x 155	ARF
Dig-15	Dig-15	Dig	Ordnance	155-mm fired fuzed	4.49			-0.315		90 NU	Not weigh	840 x 155	ARF
Dig-16	Dig-16	Dig	Ordnance	155-mm fragment	1.54			-0.03	NA	NA	22320	310 x 20 x	ARF
Dig-17	Dig-17	Dig	Ordnance	155-mm fragment	1.72			0.273	NA	NA	21400	670 x 230	ARF
Dig-18	Dig-18	Dig	Ordnance	155-mm M107 projectile, unfuzed	3.13			0.146	W	0			ARF
Dig-19	Dig-19	Dig	Ordnance	155-mm projectile	1.57			0.206		70 ND	Not weigh	610 x 155	ARF
Dig-20	Dig-20	Dig	Ordnance	155-mm projectile base	1.57			0.478	NA	NA		240 x 155	ARF
Dig-21	Dig-21	Dig	Ordnance	155-mm projectile fuzed, fired	1.73			-0.473	N	NU 75	Not weigh	660 x 155	ARF
Dig-22	Dig-22	Dig	Ordnance	155-mm projectile fuzed, fired	1.66			-0.984	ENE	80 ND	Not weigh	660 x 155	ARF

Dig-23	Dig-23	Dig	Ordnance	155-mm projectile identified	1.50			90 ND	Not recovered		ARF
Dig-24	Dig-24	Dig	Ordnance	155-mm projectile, fired, fuzed	1.85	0.329	NW	20 ND			ARF
Dig-25	Dig-25	Dig	Ordnance	155-mm projectile, fired, unfuzed	1.63	0.087	N	5 ND	Not weigh	625 x 155	ARF
Dig-26	Dig-26	Dig	Ordnance	155-mm projectile, fuzed, fired	1.59	-0.008	N	85 NU	Not weigh	660 x 155	ARF
Dig-27	Dig-27	Dig	Ordnance	155-mm projectile, fuzed, fired	1.86	-0.183	WSW	65 ND	Not weigh	750 x 155	ARF
Dig-28	Dig-28	Dig	Ordnance	155-mm projectile, fuzed, fired	1.82	0.412	N	10 NU		810 x 155	ARF
Dig-29	Dig-29	Dig	Ordnance	155-mm projectile, fuzed, fired	1.49	-0.439		90	Not weigh	625 x 155	ARF
Dig-30	Dig-30	Dig	Ordnance	155-mm projectile, fuzed, fired	1.55	-0.06	SSE	0	Not weigh	840 x 155	ARF
Dig-31	Dig-31	Dig	Ordnance	155-mm projectile, fuzed, fired	1.98	-0.501	N	45 NU	Not weigh	700 x 155	ARF
Dig-32	Dig-32	Dig	Ordnance	155-mm projectile, fuzed, fired	1.80	0.158	SW	10 NU	Not weigh	625 x 155	ARF
Dig-33	Dig-33	Dig	Ordnance	155-mm projectile, fuzed, fired	1.72	0.002	WSW	5 ND	Not weigh	711 x 155	ARF
Dig-34	Dig-34	Dig	Ordnance	155-mm projectile, fuzed, fired	1.61	-0.159	NE	45 ND	Not weigh	390 x 155	ARF
Dig-35	Dig-35	Dig	Ordnance	155-mm projectile, uncovered but not recovered	1.82	-0.563	Lost	75 ND			ARF
Dig-36	Dig-36	Dig	Ordnance	155-mm projectile, unfuzed, fired	2.16	0.524	ENE	NU 15	Not weigh	711 x 155	ARF
Dig-37	Dig-37	Dig	Ordnance	155-mm projectile, unfuzed, fired	2.20	0.674	ENE	NU 15	Not weigh	609 x 155	ARF
Dig-38	Dig-38	Dig	Ordnance	155-mm projectile. frag	2.17	-0.246	S	45 NU	17800	540 x 250	ARF
Dig-39	Dig-39	Dig	Ordnance	155-mm projectile. unfuzed fired	1.41	-0.027	NE	15 NU	Not weigh	720 x 155	ARF
Dig-40	Dig-40	Dig	Ordnance	155-mm projectile. unfuzed fired	1.64	0.353	E	85 NU	Not weigh	680 x 155	ARF
Dig-41	Dig-41	Dig	Ordnance	155-proj	1.60	-0.061	NE	5 ND	Not weighed		ARF
Dig-42	Dig-42	Dig	Ordnance	165-mm projectile, fired, unfuzed	1.77	-1.049	SW	15 ND	Not weigh	550 x 165	ARF
Dig-43	Dig-43	Dig	Ordnance	175-mm Projectile, fuzed, fired	1.63	0.081	SW	0	Not weigh	990 x 175	ARF
Dig-44	Dig-44	Dig	Ordnance	175-mm projectile, unfuzed, fired	1.91	0.3	NE	0	Not weigh	900 x 175	ARF

Dig-45	Dig-45	Dig	Scrap	2 metal rods	1.39	0.374	Not Recor	Not Recor	600		ARF
Dig-46	Dig-46	Dig	Ordnance	2.75 in rocket warhead fired, unfuzed	1.60	0.734	W	0	Not weigh	360 x 70 d	ARF
Dig-47	Dig-47	Dig	Ordnance	240-mm projectile, fuzed, fired	1.69	0.326	SW	0	Not weigh	Not Recor	ARF
Dig-48	Dig-48	Dig	Ordnance	25-mm cable, length unknown	1.81	0	NA	NA	Not recove	Not recove	ARF
Dig-49	Dig-49	Dig	Ordnance	5-inch projectile fired, unfuzed	1.63	0.664	SSW	15 NU	Not weigh	510 x 127	ARF
Dig-50	Dig-50	Dig	Ordnance	5-inch projectile, unfuzed, fired	2.05	-0.121	Lost	90 ND	Not weigh	550 x 125	ARF
Dig-51	Dig-51	Dig	Ordnance	75-mm projectile, fuzed, fired	2.29	-0.056	NNW	10 ND	Not weigh	360 x 75 d	ARF
Dig-52	Dig-52	Dig	Ordnance	75-mm projectile, fuzed, fired	1.84	0.3	SSE	0	Not weigh	420 x 75	ARF
Dig-53	Dig-53	Dig	Ordnance	75-mm projectile, fuzed, fired	1.82	-0.419	S	5 NU		360 x 75 d	ARF
Dig-54	Dig-54	Dig	Ordnance	8-in Projectile, fuzed, fired	2.19	0.008	ESE	5 NU	Not weigh	870 x 240	ARF
Dig-55	Dig-55	Dig	Ordnance	8-inch projectile	1.50	-0.209	Lost	10 NU	~ 90900	813 x 203	ARF
Dig-56	Dig-56	Dig	Ordnance	8-inch projectile, unfired (salute rd)	1.83	-0.008	N	5 ND	Not weigh	400 x 200	ARF
Dig-57	Dig-57	Dig	Ordnance	8-inch projectile, unfuzed, fired	1.77	0.114	ENE	45 NU	Not weigh	1050 x 20	ARF
Dig-58	Dig-58	Dig	Ordnance	90-mm AP round fired	1.63	-0.095	SW	30 ND			ARF
Dig-59	Dig-59	Dig	Ordnance	90-mm projectile	2.58	0.427	N	0	Not weigh	400 x 90 d	ARF
Dig-60	Dig-60	Dig	Ordnance	90-mm projectile	1.85	0.123	SW	15 ND	7400	270 x 90 d	ARF
Dig-61	Dig-61	Dig	Ordnance	90-mm projectile casing, unfuzed	2.63	-0.073	S	ND 15	Not weigh	270 x 90 d	ARF
Dig-62	Dig-62	Dig	Ordnance	90-mm Projectile, fuzed, fired	1.32	-0.111	NNE	75 NU	Not weigh	310 x 90 d	ARF
Dig-63	Dig-63	Dig	Ordnance	90-mm Projectile, fuzed, fired	1.53	0.058	SW	0	Not weigh	310 x 90(d	ARF
Dig-64	Dig-64	Dig	Ordnance	90-mm projectile, fuzed, fired	2.31	0.001	SE	15 ND	Not weighed		ARF
Dig-65	Dig-65	Dig	Ordnance	90-mm projectile, fuzed, fired	1.76	0.007	NE	50 NU	Not weigh	382 x 90 d	ARF
Dig-66	Dig-66	Dig	Ordnance	90-mm projectile, unfired, unfuzed	1.55	0.33	NE	10 ND	Not weigh	200 x 90 d	ARF
Dig-67	Dig-67	Dig	Ordnance	90-mm projectile., fuzed	1.48	1.169	SW	0	Not weigh	356 x 90 d	ARF
Dig-68	Dig-68	Dig	Ordnance	90-mm projectile.,	1.74	-0.116	E	10 NU	Not weigh	390 x 90 d	ARF

				fuzed fired								
Dig-69	Dig-69	Dig	Ordnance	90-mm projectile., unfuzed fired	1.77		0.488	W	25 NU	Not weigh	420 x 90 d	ARF
Dig-70	Dig-70	Dig	Scrap	Banding	1.38			NA	NA	Lost	Lost	ARF
Dig-71	Dig-71	Dig	Scrap	Bar stock	1.24	-7.24	0.1028	NA	NA	1160	670 x 30 x	AF
Dig-72	Dig-72	Dig	Frag	Baseplates	1.19		0.109	NA	NA	3210 total	125 dia x	ARF
Dig-73	Dig-73	Dig	Frag	Bomb fragment	1.93		0.067	NA	NA	25300	710 x 590	ARF
Dig-74	Dig-74	Dig	Frag	Bomb fragments	2.22		0.577	NA	NA	9200	730 x 220	ARF
Dig-75	Dig-75	Dig	Frag	Bomb plug	1.90		0.29			1060	33 x 85 dia	ARF
Dig-76	Dig-76	Dig	Ordnance	Butterfly bomb	1.56		0.01	NA	NA	200	230 x 200	ARF
Dig-77	Dig-77	Dig	Scrap	Cable	1.34	187.39	0.21664	NA	NA	830	1020	AF
Dig-78	Dig-78	Dig	Frag	Closing plug	1.55			NA	NA	300	30 x 60 dia	ARF
Dig-79	Dig-79	Dig	Scrap	Cylinder	1.53		0.058	NA	NA			ARF
Dig-80	Dig-80	Dig	Scrap	Cylinder	1.44		0.223			5900	310 x 90 d	ARF
Dig-81	Dig-81	Dig	Scrap	Cylinder	1.61		0.302	Not Recor	Not Recor	3060	190 x 100	ARF
Dig-82	Dig-82	Dig	Scrap	Deep target	1.61			NA	NA	Not recovered		ARF
Dig-83	Dig-83	Dig	Scrap	Flat stock	1.44	-0.47	-0.2748	NA	NA	160	115 x 30 x	AF
Dig-84	Dig-84	Dig	Frag	Frag, base of 155	1.78		0.234	NA	NA	3060	65 x 165 d	ARF
Dig-85	Dig-85	Dig	Frag	Fragment	1.63		Lost	NA	NA	2600	220 x 180	ARF
Dig-86	Dig-86	Dig	Frag	Fragment	1.67		0.601	NA	NA	3560	335 x 170	ARF
Dig-87	Dig-87	Dig	Frag	Fragment	1.59		0.011	NA	NA	3890	300 x 140	ARF
Dig-88	Dig-88	Dig	Frag	Fragment	1.41		0.15	S	70 NU	7370	450 x 110	ARF
Dig-89	Dig-89	Dig	Frag	Fragment	1.75		0.822	NA	NA	2020	225 x 125	ARF
Dig-90	Dig-90	Dig	Frag	Fragment	1.85		-0.052	NA	NA	5850	330 x 140	ARF
Dig-91	Dig-91	Dig	Frag	Fragment	2.20		0.533	E	85 NU	Not recove	60 x 150	ARF
Dig-92	Dig-92	Dig	Frag	Fragment	1.47		0.027	NA	NA	1670	150 x 120	ARF
Dig-93	Dig-93	Dig	Frag	Fragment	1.40		0.318	NA	NA	2030	45 x 150 d	ARF
Dig-94	Dig-94	Dig	Frag	Fragment	1.46		0.111	NA	NA	2830	210 maj di	ARF
Dig-95	Dig-95	Dig	Frag	Fragment	2.26		0.161	NA	NA	4120	260 x 110	ARF
Dig-96	Dig-96	Dig	Frag	Fragment	1.86		0.643	NA	NA	2200 total	190 x 90 x	ARF
Dig-97	Dig-97	Dig	Frag	Fragment	1.74		0.502	NA	NA	5200	170 x 180	ARF
Dig-98	Dig-98	Dig	Frag	Fragment	1.44		0.43	NA	NA	3480	220 x 120	ARF

Dig-99	Dig-99	Dig	Frag	Fragment	1.76		0.06	NA	NA	1400	310 x 80 x	ARF
Dig-100	Dig-100	Dig	Frag	Fragment	2.62		0.672	NA	NA	1830	240 x 90 x	ARF
Dig-101	Dig-101	Dig	Frag	Fragment	1.90		0.075	NA	NA	4600	220 x 160	ARF
Dig-102	Dig-102	Dig	Frag	Fragment	1.43		0.241	NA	NA	1000	270 x 150	ARF
Dig-103	Dig-103	Dig	Frag	Fragment	1.78		0.044	NA	NA			ARF
Dig-104	Dig-104	Dig	Frag	Fragment	1.82		0.404	NA	NA	560	80 x 60 x	ARF
Dig-105	Dig-105	Dig	Frag	Fragment	1.46		0.389	NA	NA		150 x 150	ARF
Dig-106	Dig-106	Dig	Frag	Fragment	1.47		0.101	NA	NA	725 total	100 x 80 x	ARF
Dig-107	Dig-107	Dig	Frag	Fragment	1.89		0.834	NA	NA	1600	250 x 90 x	ARF
Dig-108	Dig-108	Dig	Frag	Fragment	1.89		0.255	NA	NA	900	130 x 80 x	ARF
Dig-109	Dig-109	Dig	Frag	Fragment	1.40		-0.465	NA	NA	660	100 x 50 x	ARF
Dig-110	Dig-110	Dig	Frag	Fragment	1.91		-0.043	NA	NA	2200	320 x 80 x	ARF
Dig-111	Dig-111	Dig	Frag	Fragment	1.48		0.222	NA	NA	1100	100 x 70 x	ARF
Dig-112	Dig-112	Dig	Frag	Fragment	1.89		0.648	NA	NA	2150	320 x 90 x	ARF
Dig-113	Dig-113	Dig	Frag	Fragment	1.93		0.048	NA	NA	2710	210 x 110	ARF
Dig-114	Dig-114	Dig	Frag	Fragment	1.76		-0.04	NA	NA	3220	30 x 155 d	ARF
Dig-115	Dig-115	Dig	Frag	Fragment	1.99		-0.081	NA	NA	2600	210 x 120	ARF
Dig-116	Dig-116	Dig	Frag	Fragment cloud	1.56		0.03	NA	NA	Not weigh	Not Recor	ARF
Dig-117	Dig-117	Dig	Frag	Fragment, unreliable re-covery data, de-mil area	3.11		0.246	NA	NA	820	130 x 100	ARF
Dig-118	Dig-118	Dig	Frag	Fragments	1.67		-0.05	NA	NA	4600 total	280 x 100	ARF
Dig-119	Dig-119	Dig	Frag	Fragments	1.89		0.92	NA	NA	10100 total	390 x 180	ARF
Dig-120	Dig-120	Dig	Frag	Fragments	2.22		-0.024	NA	NA	5800	300 x 120	ARF
Dig-121	Dig-121	Dig	Frag	Fragments	1.45		0.061			3100	lost	ARF
Dig-122	Dig-122	Dig	Frag	Fragments	1.69		0.38	NA	NA	2320	Not Recor	ARF
Dig-123	Dig-123	Dig	Frag	Fragments	1.64		0.427	NA	NA	640 total	90 x 60 x	ARF
Dig-124	Dig-124	Dig	Frag	Fragments	1.50		0.123	NA	NA	Not Recor	Not Recor	ARF
Dig-125	Dig-125	Dig	Frag	Fragments	1.77		0.177	NA	NA			ARF
Dig-126	Dig-126	Dig	Frag	Fragments	1.64		0.823	NA	NA	3800		ARF
Dig-127	Dig-127	Dig	Frag	Fragments	1.45		0.423	NA	NA	2950 total	320 x 80 x	ARF
Dig-128	Dig-128	Dig	Frag	Fragments	1.78		0.282	NA	NA	4620 total	260 x 100	ARF

Dig-129	Dig-129	Dig	Frag	Fragments	2.12		-0.324	NA	NA	4150		ARF
Dig-130	Dig-130	Dig	Frag	Fragments	2.05		0.025	NA	NA	9760	270 x 130	ARF
Dig-131	Dig-131	Dig	Frag	Fragments	1.88		0.035	NA	NA	800 total	180 x 35 x	ARF
Dig-132	Dig-132	Dig	Frag	Fragments (3)	1.68		-0.027	NA	NA	Lost	Lost	ARF
Dig-133	Dig-133	Dig	Frag	Fragments (low order detonation.)	2.25		0.119	NA	NA	15160		ARF
Dig-134	Dig-134	Dig	Frag	Fragments and rebar	1.87		0.024	Not Recor	Not Recorded			ARF
Dig-135	Dig-135	Dig	Frag	Fragments from 90-mm projectile	2.04		0.357			6000		ARF
Dig-136	Dig-136	Dig	Frag	Fragments, unreliable recovery data, area disturbed by explosive testing after survey	2.40		0.734	NA	NA	110	Not Recor	ARF
Dig-137	Dig-137	Dig	Ordnance	Fused 155-mm projectile	1.70		0.609	N	0	Not weigh	720 x 155	ARF
Dig-138	Dig-138	Dig	Ordnance	Fuze	2.08		-0.034	NA	NA			ARF
Dig-139	Dig-139	Dig	Scrap	Handle	0.98	0.88	0.29856	NA	NA	95	245 x 30 x	AF
Dig-140	Dig-140	Dig	Scrap	Household waste pile, metal pitcher, cups, wash buckets, misc. scrap metal	1.58		0.738	NA	NA	Not Recor	Not Recor	ARF
Dig-141	Dig-141	Dig	Frag	Large fragment	2.03		0.918	NA	NA			ARF
Dig-142	Dig-142	Dig	Frag	Large piece of 4 (102-mm) angle iron	2.37		-0.771	Lost	10	Not recove	12 mm thi	ARF
Dig-143	Dig-143	Dig	Scrap	Large piece of angle iron	1.56		0.025	NE	0	11000	740 x 90 x	ARF
Dig-144	Dig-144	Dig	Frag	Large piece of fragment	1.97		0.283	NA	NA	12400	630 x 460	ARF
Dig-145	Dig-145	Dig	Frag	Large, thin-wall (bomb?) frag, unable to recover	1.58					Not weigh	Not recove	ARF
Dig-146	Dig-146	Dig	Ordnance	Low-order 90 or 105 mm projectile	1.83		-0.122	SW	NU 85	11300	320 x 180	ARF
Dig-147	Dig-147	Dig	Scrap	Mower blade	1.37	1.92	- 0.14764	NA	NA	1405	330 x 70 x	AF
Dig-148	Dig-148	Dig	Scrap	Pipe & Ring	1.35	-0.16	-0.0568	NA	NA	840	420 x 30	AF
Dig-149	Dig-149	Dig	Scrap	Pipe & Ring	1.71		-0.034	NA	NA	8340	Not Recor	ARF
Dig-150	Dig-150	Dig	Frag	Projectile frag (90-mm) /w fuze	1.69		0.123	E	15 NU	7500	400 x 180	ARF
Dig-151	Dig-151	Dig	Frag	Projectile fragment	1.70		-0.121	N	75 NU	16130	500 x 160	ARF

Dig-152	Dig-152	Dig	Frag	Projectile fragment	1.43		0.078	NA	NA	4800	300 x 110	ARF
Dig-153	Dig-153	Dig	Frag	projectile fragments	2.07		0.617	NA	NA	19670 total	Various	ARF
Dig-154	Dig-154	Dig	Frag	Projectile fragments	1.62		-0.021	NA	NA	6350 total	360 x 120	ARF
Dig-155	Dig-155	Dig	Scrap	Railroad rail on end	1.48		0.281	Lost	15	Not recovered		ARF
Dig-156	Dig-156	Dig	Scrap	Railroad spike	1.98		0.245	SE	45	1300	360 x 30 x	ARF
Dig-157	Dig-157	Dig	Scrap	Rebar in concrete	1.76		-0.106	E	0	Not Recor	2 ea 32 di	ARF
Dig-158	Dig-158	Dig	Ordnance	Rocket, unfuzed, fired	1.54		0.051	NE	30 ND			ARF
Dig-159	Dig-159	Dig	Frag	Scattered small fragments	2.31		0.856	NA	NA			ARF
Dig-160	Dig-160	Dig	Scrap	Scrap	1.34	0.83	-0.12192	NA	NA	285	160 x 70	AF
Dig-161	Dig-161	Dig	Scrap	Scrap from steal drum	1.40	9.44	-0.39672	NA	NA	3255	Not Recor	AF
Dig-162	Dig-162	Dig	Scrap	Scrap iron	1.41	0.14	-0.08534	NA	NA	1025	180 x 50 x	AF
Dig-163	Dig-163	Dig	Scrap	Scrap iron	1.37	-4.83	0.25712	NA	NA	8100	8315 x 12	AF
Dig-164	Dig-164	Dig	Scrap	Scrap iron	1.17	-0.41	-0.1324	NA	NA	405	560	AF
Dig-165	Dig-165	Dig	Scrap	Scrap metal	1.91		0.074	NA	NA	640	300 x 40 x	ARF
Dig-166	Dig-166	Dig	Scrap	Scrap metal	2.27		0.079	NA	NA	1240 total	230 x 30 x	ARF
Dig-167	Dig-167	Dig	Scrap	Scrap metal	2.62		0.672	NA	NA	1250	590 x 60 x	ARF
Dig-168	Dig-168	Dig	Frag	Small fragments	1.64		0.495	NA	NA	Lost	Lost	ARF
Dig-169	Dig-169	Dig	Frag	Small frags	1.23		0.071	NA	NA	325 total	110 x 50 x	ARF
Dig-170	Dig-170	Dig	Frag	Small frags, unreliable reco- very data, in de-mil area	1.61		0	NA	NA	Not recove	Not Recor	ARF
Dig-171	Dig-171	Dig	Scrap	Spring	1.32	-0.83	-0.13716	NA	NA	100	190 x 40	AF
Dig-172	Dig-172	Dig	Scrap	Steel core ground rod, approx 0.6 meters bent to ground surface ~1.2m in	1.63		0.896	NA	0			ARF
Dig-173	Dig-173	Dig	Scrap	Steel fragment	2.02		0.279	NA	NA	1420	180 x 80 x	ARF
Dig-174	Dig-174	Dig	Scrap	Steel plate	1.56		0.799	NA	0	490000 (e	1829 x 18	ARF
Dig-175	Dig-175	Dig	Scrap	Steel plate	1.84		0.678	NA	90	5236000 (	1829 x 18	ARF
Dig-176	Dig-176	Dig	Scrap	Steel Plate	1.70		0.075	NA	NA			ARF

Dig-177	Dig-177	Dig	Scrap	Steel plate	1.63		-0.912	NA	90	13110	580 x 180	ARF
Dig-178	Dig-178	Dig	Ordnance	Suspect Ammo Burial Pit below recovered	1.56		-0.395	NA	NA			ARF
Dig-179	Dig-179	Dig	Scrap	Thin walled cylinder	1.71		0.264	NE	45 D	1830	300 x 100	ARF
Dig-180	Dig-180	Dig	Practice	Two inert mines (Volcano)	1.30	4.80	0.09808	NA	NA	3420	120 dia x	AF
Dig-181	Dig-181	Dig	Scrap	Unknown	1.84		0.082	NA	NA	8490	320 x 240	ARF
Dig-182	Dig-182	Dig	Scrap	Unknown	1.52		0.106	NA	NA	1960	150 x 220	ARF
Dig-183	Dig-183	Dig	Scrap	Welding rods	1.20	0.40	-0.00764	NA	NA	50	480	AF
Dig-184	Dig-184	Dig	Scrap	Welding rods	1.13	0.30	-0.38816	NA	NA	5	240	AF
Dig-185	Dig-185	Dig	Scrap	Wire	1.39	-0.65	0.16	NA	NA	15	910	AF
Dig-186	Dig-186	Dig	Scrap	Wire	1.21	0.10	-0.18288	NA	NA	60	1070	AF
Dig-187	Dig-187	Dig	Scrap	Wire	1.06	6.37	0.29418	NA	NA	525	960	AF
Dig-188	Dig-188	Dig	Scrap		1.83		0.463	NA	NA		120 x 105	ARF
Dig-189	Dig-189	Dig	Scrap		1.76		0.773	NA	NA		310 x 95 x	ARF